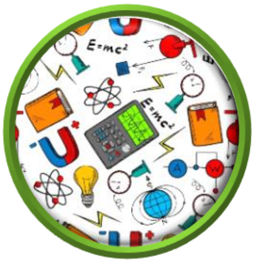
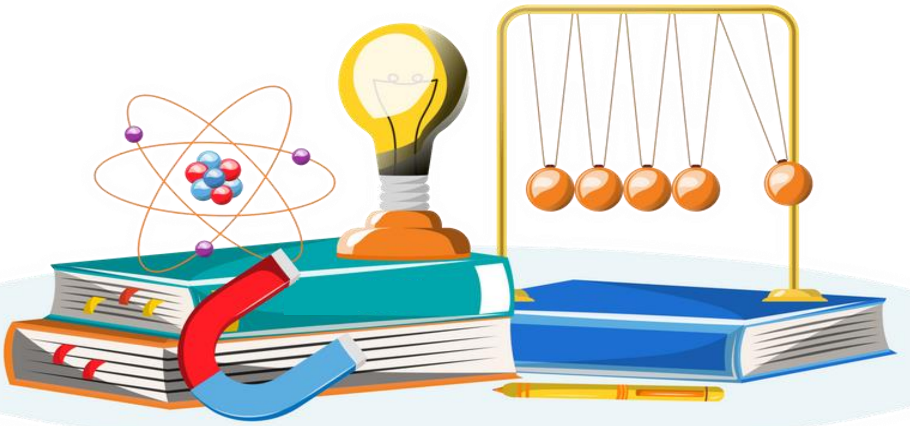
PHYSICS

312

Total no. of Lessons – 30		
MODULE (No. & name)	**TMA (40%)**	**Public Examination (60%)**
	(No. of lessons-12)	**(No. of lessons-18)**
1. Force and Energy	L-1 (Units Dimensions and Vectors) L-2 (Motion in a Straight Line) L-4 (Motion in a Plane) L-5 (Gravitation) L-7 (Motion of a Rigid Body)	L-3 (Laws of Motion) L-6 (Work, Energy and Power)
2. Mechanics of Solids and Fluids	L-8 (Elastic Properties of Solids)	L-9 (Properties of Fluids)
3. Thermal Physics	L-10 (Kinetic Theory of Gases) L-12 (Heat Transfer and Solar Energy)	L-11 (Thermodynamics)
4. Oscillations and Waves	L-13 (Simple Harmonic Motion)	L-14 (Wave Phenomena)
5. Electricity and Magnetism	–	L-15 (Electric Charge andElectric Field) L-16 (Electric Potential and Capacitors) L-17 (Electric Current) L-18 (Magnetism and Magnetic Effect of Electric Current) L-19 (Electromagnetic Induction and Alternating Current)
6. Optics and Optical Instruments	L-20 (Reflection and Refraction of Light) L-23 (Optical Instruments)	L-21 (Dispersion and Scatteringof Light) L-22 (Wave Phenomena and Light)
7. Atoms and Nuclei	–	L-24 (Structure of Atoms) L-25 (Dual Nature of Radiationand Matter) L-26 (Nuclei and Radioactivity) L-27 (Nuclear Fission and Fusion)
8. Semiconductor Devices and Communication	L-30 (Communication System)	L-28 (Semiconductors and Semiconducting Devices) L-29 (Applications of Semiconductor Devices)





Sl. No.	Type of Question	No. of questions	Marks
1.	MCQ (1 mark) #	16	16
2.	Objective Type Questions (1*2 = 2 marks) ## (with 2 sub-parts of 1 mark each) [Fill in the blanks, match the column, paragraph or case-based questions, one-word questions, True False, etc.]	12	24
	Total	**28**	**40**
3.	Very Short Answer (2 marks)	9	18
4.	Short Answer (SA) (3 marks)	4	12
5.	Long Answer (LA) (5 marks)	2	10
	Total	**15**	**40**
	G. Total	**43**	**80**

Weightage to difficulty level of question

Estimated Level	Marks	Percentage of marks
Difficulty	16	20
Average	40	50
Easy	24	30
Total	**80**	**100**

Weightage by Content

Sl.	Module	Marks
1.	Motion Force and Energy	14
2.	Mechanics of solid and Fluid	06
3.	Thermal Physics	06
4.	Oscillation and Wave	06
5.	Electricity and Magnetism	16
6.	Optics and Optical Instruments	14
7.	Atoms and Nuclei	08
8.	Semiconductor Devices and Communication	10
	Total	**80**

CHAPTER: 3

LAWS OF MOTION

Question 1: charge in momentum of a body is: **[PYQ Oct 2022]**

(a) Force × displacement (b) mass × displacement

(c) force × time (d) force × velocity

Answer: (c) force × time

Explanation: According to Newton's second law

$$F_{ex} \propto \frac{\Delta p}{\Delta t} \Rightarrow \Delta p = F_{ex} \times \Delta t$$

Hence, change in momentum = Δp = force × time

Question 2: Define the term impulse. Give its S.I. unit. **[PYQ Oct 2022]**

Answer: The impulse is defined as "the product of force and time, which is change in momentum of the body."

$$\mathbf{I = F.\ \Delta t}$$

S.I. unit of impulse is **Newton × sec**.

Question 3: A body of mass m is thrown vertically up with velocity v. it returns back to the thrower with the same velocity. Calculate:

(i) Change in momentum.

(ii) Change in magnitude of momentum of the body. **[PYQ April 2022]**

Answer: (i) P = mv

$P_{initial} = mv$ and $P_{final} = mv$

Change in momentum = $P_{initial} - P_{final} = mv - mv = \mathbf{0}$

(ii) change in magnitude of momentum = **0**

Question 4: State Newton's three laws of motion. **[PYQ April 2022]**

Answer:

Newton's three laws of motion are:

1. First law of motion or law of inertia: An object at rest will stay at rest, and an object in motion will stay in motion with the same speed and in the same direction, unless acted upon by an unbalanced force.

2. Second law of motion or law of acceleration: The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

3. Third law of motion or law of action to reaction: For every action, there is an equal and opposite reaction.

Question 5: Starting from the third law of motion, derive the law of conservation of linear momentum. **[PYQ April 2022]**

Answer:

Newton’s third law states that for a force applied by an object A on object B, object B exerts back an equal force in magnitude, but opposite in direction.

Consider two colliding particles A and B whose masses are m_1 and m_2 with initial and final velocities as u_1 and v_1 of A and u_2 and v_2 of B. The time of contact between two particles is given as t.

$$A = m_1(v_1 - u_1)$$

(change in momentum of particle A)

$$B = m_2(v_2 - u_2)$$

(change in momentum of particle B)

$$F_{BA} = -F_{AB}$$

(from third law of motion)

$$F_{BA} = m_2 * a_2 = \frac{m_2(v_2-u_2)}{t}$$

$$F_{AB} = m_1 * a_1 = \frac{m_1(v_1-u_1)}{t}$$

$$\frac{m_2(v_2-u_2)}{t} = \frac{-m_1(v_1-u_1)}{t}$$

$$\boxed{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$$

$m_1u_1 + m_2u_2$ is the momentum of A and B before collision and $m_1v_2 + m_2v_2$ is the momentum of A and B after collision.

So we can say that momentum is conserved.

Question 6: A ball of mass ‘m’ strikes a rigid wall with the speed ‘u’ and rebounds back with the same speed. The impulse imparted to the ball by the wall is:

(a) 2mu (b) mu (c) 0 (d) -2mu **[PYQ Oct 2021]**

Answer: **(d) -2mu**

Explanation: $P_{initial} = mu$ and $P_{final} = -mu$

We know that impulse = change in momentum

$\Rightarrow$ Impulse = $P_{final} - P_{initial} = -mu - mu = -2mu$

Question 7: Define:

(a) coefficient of friction and

(b) coefficient of kinetic friction. **[PYQ Oct 2021]**

Answer:

Coefficient of friction –: The coefficient of friction **(μ)** between two surfaces is the ratio of their limiting frictional force to the normal force between them.

$$\mu = \frac{\text{limiting frictional force}}{\text{normal reaction}} = \frac{F}{R}$$

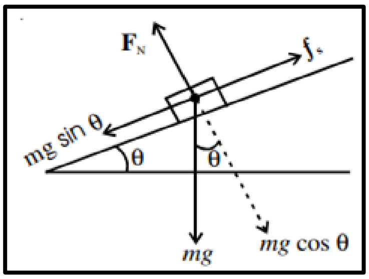
Coefficient of kinetic friction –: the coefficient of kinetic friction **(μ_s)** between two surfaces is the ratio of force of kinetic friction to the normal force between them.

$$\mu_s = \frac{\text{kinetic frictional force}}{\text{normal reaction}} = \frac{F_k}{R}$$

Question 8: A block of mass ‘m’ is held on a rough inclined surface of inclination θ, show in diagram various forces acting on the block.

[PYQ Oct 2021]

Answer:



Question 9: State Newton’s first law of motion. Define inertia. Which physical quantity is a measure of the inertia of a body?

Is it correct to say that a body always moves in the direction of external force acting on it? Give reasons therefore. **[PYQ Oct 2021]**

Answer:

Newton’s first law of motion: An object at rest remains at rest, or if in motion, remains in motion until an external force does not applied on it.

Inertia: Everybody has a property that it always opposes its change in position , this property is called **Inertia.**

Inertia is the measure of mass of the object.

It is not correct to say that a body always moves in the direction of external force acting on it. The statement is true only for a body which was at rest before the application of force.

Question 10: State Newton’s third law of motion. What is the vectorial form of Newton’s third law of motion? **[PYQ Oct 2021]**

Answer: Newton’s third law of motion –:

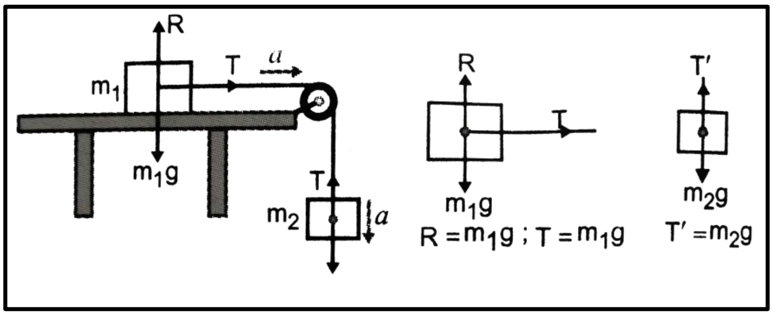
1. It states that “To every action, there is an equal and opposite reaction”.

2. When two objects interact with each other, the force exerted by the first object on the second is referred to as action. The reaction force is the force exerted by the second body on the first body. Therefore, the action and reaction are opposite and equal in magnitude.

Vectorial form of third law –: $\overrightarrow{\mathbf{F_{12}}} = -\overrightarrow{\mathbf{F_{21}}}$

Question 11: A body of mass m_1 = 10 kg is placed on a smooth horizontal table. It is connected to a pulley string which passes over a frictionless pulley and carries at the other end a body m_2 of mass 5kg. Calculate. (i) Acceleration of the bodies and (ii) Tension in the string when m_2 is let free. Take g = 9.8 N/k. **[PYQ JAN 2021]**

Answer: refer to fig.→



According to Newton’s second law of motion: F = ma

Here, $(m_1 + m_2)\,a = m_2g$

$$\Rightarrow\ a = \frac{m_2 g}{(m_1+m_2)}$$

$$\Rightarrow\ a = \frac{5\times 9.8}{(10+5)} = \frac{49}{15} = \mathbf{3.27\ m/s^2}$$

Question 12: An object is moving at a constant speed in a circular path. Does the object have constant momentum? Give reason for your answer.

Answer: No. Though the speed is constant, the velocity of the object changes due to change in direction. Hence its momentum will not be constant.

Question 13: Two masses m_1 and m_2 ($m_1 > m_2$) are connected at the two ends of a light inextensible string that passes over a light frictionless fixed pulley. Find the acceleration of the masses and the tension in the string connecting them when the masses are released.

Answer: When the masses are released, the acceleration of the system can be found using the equation: F = ma $\Rightarrow (m_1 - m_2)\times g = (m_1 + m_2)\,a$

$$\Rightarrow\quad \mathbf{a} = \frac{(m_1-m_2)g}{m_1+m_2}$$

where m_1 and m_2 are the masses, and g is the acceleration due to gravity.

The tension in the string can be found using the equation:

$$\text{tension} = m_1 \times a = \mathbf{m_1} \times \frac{(m_1-m_2)g}{m_1+m_2}$$

Question 14: In which case will there be larger change in momentum of a 2 kg object:

(a) When 10 N force acts on it for 1s?
(b) When 10 N force acts on it for 1m?
Calculate change in momentum in each case.

Answer: The change in momentum of an object can be calculated using the formula:

Change in momentum = force × time

In option A, Change in momentum = 10 N × 1 s = **10 kg·m/s**

In option B, the force is 10 N and the distance is 1 meter. To calculate the change in momentum, we need to use the formula:

Change in momentum = force × distance

In option B, Change in momentum = 10 N × 1 m = **10 kg·m/s**

So, in both cases, the change in momentum of the 2 kg object would be the same, which is 10 kg·m/s.

Question 15: A 5 kg block is resting on a horizontal surface for which $\mu k = 0.1$. What will be the acceleration of the block if it is pulled by a 10 N force acting on it in the horizontal direction?

Answer: Acceleration = force / mass

Substituting the values, we get:

$$a = 10\text{ N} / 5\text{ kg} = \mathbf{2\ m/s^2}$$

Therefore, the acceleration of the block will be 2 m/s^2 when a 10 N force is applied to it in the horizontal direction.

LAWS OF MOTION

Short summary

What do we learn

Quick Revision

Force and motion

To move any object or body we have to exert force on it. It is exerted by external source.

Newton's laws of motion

After failure of Galileo and Aristotle, Isaac Newton gave three laws of motion:

1. First law of motion or law of inertia
2. Second law of motion or law of acceleration.
3. Third law of motion or action to reaction law.

Inertia

Everybody has a property that it always opposes its change in position, this property is called **Inertia.**

- Two bodies of equal mass possess same inertia because it is a factor of mass only.

- Inertia is the measure of mass of the object.

First law of motion

- Everybody continues to be in its state of rest or of uniform motion in a straight line unless compelled by some external force to act otherwise.

- Simply, ***"If an object is at rest or in uniform motion, then it will remain at rest or in uniform motion until an external force does not applied to it."***

Types of inertia

Inertia are of three types :

a) **INERTIA OF REST:** If an object is at rest, then it will remain in at rest till an external force doesn't apply to it.

Example -: when a bus is at rest and if suddenly it starts moving then passengers feel a force backward.

b) **INERTIA OF MOTION:** If an object is in uniform motion, then it will remain in motion till an external force doesn't apply on it.

Example -: A moving bus suddenly stops and passengers feel a force forward.

c) **INERTIA OF DIRECTION**: if an object is moving in certain direction, then it will remain in this direction unless an external force does not apply to it.

Example -: When a vehicle tier moves in mud then, particles of mud move in tangential direction.

➢ Momentum

- Momentum of a body is the quantity of motion contained in the body.

- It is measured as the product of the mass of the body and its velocity.

Momentum = mass × velocity

- If a body of mass m is moving with velocity $\vec{v}$ then its momentum $\vec{v}$ is given by: $\vec{p} = m\vec{v}$

- It is a vector quantity and it's direction is the same as the direction of velocity of the body.

- Unit: $\frac{kg \times m}{sec}$
- Dimension: **[MLT^{-1}]**

➢ Second law of motion

- The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts.

- Simply expressed as ***"the external force apply to an object is directly proportional to the change in the momentum."***

$$F_{ex} \propto \frac{\Delta p}{\Delta t} \qquad F_{ex} = k\frac{\Delta p}{\Delta t}$$

Where **k** is the constant of proportionality.

k = 1 for S.I. & C.G.S. unit

$$F = ma$$

➢ Applications of second law of motion

1. Cricket player lowers his hand while catching the ball.
2. A karate player can break a pile of tiles with a single blow of his hand.
3. In a high jump athletic event, the athletes are allowed to fall either on a sand bed or cushioned bed.

➢ Impulse

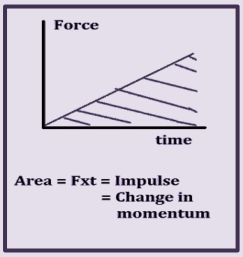
- Forces acting for a short time are called IMPULSIVE FORCE.

- it is measured as **"the product of force and time, which is change in momentum of the body."**

Impulse = force × time

$$I = \int F\,dt \Rightarrow I = F.\,\Delta t$$

- Impulse is a vector quantity. Its direction is same as that of force.
- Unit: N × sec
- Dimensional formula: **(MLT^{-1}).**
- Force-time graph- Impulse is equal to the area under F-t curve.



Third law of motion

- Third law is states as "**to every action, there is always an equal and opposite reaction.**"

Let us note some important points about the third law –:

1. Forces always occur in pairs. Force on a body A by B is equal and opposite to the force on the body B by A.

2. There is no cause effect relation implied in the third law. The force on A by B and the force on B by A act at the same instant.

3. Action and reaction forces act on different bodies, not on the same body.

$$\boxed{F_{AB} = -F_{BA}}$$

(Force on A by B) = -(Force on B by A)

So this is clear that the net force is zero.

Examples of third law

1. Firing of bullet.
2. Swimming and walking.
3. Kick the ball.
4. Rocket launch.
5. Pushing a car and a truck.

Applications of third law

1. Recoiling of a gun
2. To walk, we press the ground in backward direction with foot

Law of Conservation of momentum

If external force on an object is zero then linear momentum of the object remains conserved. This is called the law of conservation of momentum.

Or, **"the total momentum of an isolated system of interchanging particles is conserved."**

$$\text{If} \quad F_{ext} = 0, \ \sum_{i=1}^{n} P_i = \text{constant} \quad \text{or} \quad P = \text{constant}$$

Equilibrium of particle

- Equilibrium of a particle in mechanics refers to the situation when the net external force on the particle is zero.

Mathematically,

$$\sum \vec{F} = 0 \quad i.e., \quad \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots\ldots = 0.$$

- If three concurrent forces $\vec{F}_1, \vec{F}_2$ and $\vec{F}_3$ act at a point and are in equilibrium, then

$$\frac{F_1}{\sin\alpha} = \frac{F_2}{\sin\beta} = \frac{F_3}{\sin\gamma}$$

where α, β and γ are angles indicated.

Friction

It is an opposing force acting at the surface of contact between the two objects or surfaces, which always opposes relative motion.

Examples of friction

1. Driving of a vehicle on a surface.
2. Applying breaks to stop a moving vehicle.
3. Skating. 4. Flying of aero planes.

➢ *Types of friction*

1. Kinetic: objects are in rest.
2. Static: objects are in motion.
3. Rolling: objects are in rolling.

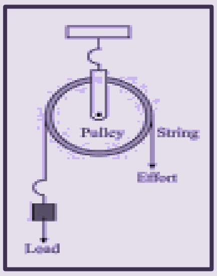
➢ *Coefficient of friction*

The coefficient of friction (μ) between two surfaces is the ratio of their limiting frictional force to the normal force between them.

$$\mu = \frac{\text{limiting frictional force}}{\text{normal reaction}} = \frac{F}{R}$$

➢ *Simple pulley*

The pulley is defined as a mechanical device that consists of a wheel and a rope. The rope is connected with wheel at it is surrounding the wheel.



Let **a** be the acceleration in this system, which is given by:

$$a = \frac{(m_1 - m_2)g}{m_1 - m_2}$$

Tension is given by: $$T = \frac{(2\, m_1 m_2)g}{m_1 + m_2}$$

➢ *Limiting frictional force*

The maximum value of static friction upto which body does not move is called limiting friction.

➢ *Frame of reference*

- A frame in which an observer is situated and makes his observations is known as his **'Frame of reference'**.

- There are two types of it:

(i) Inertial frame of reference
(ii) Non – inertial frame of reference

1. **Inertial frame:** If the observer's frame of reference is stationary or moving with a constant velocity with respect to the object (another frame of reference), such frame is called *Inertial frame.*

- An inertial frame is one in which an isolated object has zero acceleration.

2. **Non- inertial frame:** if the frame is accelerating, such frame is called *Non- Inertial frame.*

- Newton's laws of motion are applicable only in an inertial frame of reference.

➢ *Free body diagram*

By using the free body diagram, it became easy to use the Newton's laws to solve the problems in mechanics.

A diagram which shows all the forces acting on a body in a given situation is called **free body diagram(FBD).**

MCQs

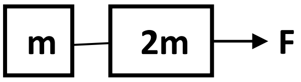
1. The maximum velocity (in m/s) with which a car driver must transverse a flat curve of radius 150 m and coefficient of friction 0.6 to avoid skidding is:

(a) 60 (b) 30

(c) 15 (d) 25

Answer: **(b) 30**

Explanation: $v = \mu rg = 0.6 \times 150 \times 10 = 30$ m/ s

2. The tension in string shown in fig  is:

(a) F/3 (b) F/6

(c) F/2 (d) 2F

Answer: **(a) F/3**

Explanation: $2ma = F - T \Rightarrow T = F/3$

3. A particle moves in x-y plane under the action of force $\vec{F}$ such that the value of its linear momentum $\vec{p}$ at any instant t is $p_x = 2 \cos t$ and $p_y = 2 \sin t$. The angle θ between $\vec{F}$ and $\vec{p}$ at a given time t will be –:

(a) 90° (b) 0°

(c) 180° (d) 30°

Answer: **(a) 90°**

4. The objects at rest suddenly explodes into three parts with the mass ratio 2:1:1. The parts of equal masses moves at right angles to each other with equal speeds. The speed of the third part after the explosion will be:

(a) 2v (b) $\frac{v}{\sqrt{2}}$

(c) $\frac{v}{2}$ (d) $\sqrt{2}v$

Answer: **(b) $\frac{v}{\sqrt{2}}$**

5. Two Iron blocks of equal masses but with double surface area slide down an Inclined plane with coefficient of friction μ. If the first block with surface area A experience a friction force f, then the second block with surface area 2A will experiences a frictional force.

(a) f/2 (b) f
(c) 2f (d) 4f

Answer: **(b) f**

Explanation: Frictional force is independent of area of contact.

6. If the tension in the cable supporting an elevator is equal to the weight of elevator, the elevator may be
(a) going up with increasing speed (b) going down with increasing speed
(c) going up with uniform speed (d) elevator falls freely under gravity

Answer: **(c) going up with uniform speed**

Explanation: Impulse = $\int F\, dt$

7. A graph is drawn with a force along y-axis and time along x-axis. The area under the graph represent–
(a) Momentum (b) Couple
(c) Moment of the force (d) Impulse of the force

Answer: **(d) impulse of the force**

8. In a game of tug of wars, a condition of equilibrium exists. Both the team pull the rope with a force of 10^4 N. The tension in the rope is –:
(a) 10^4 N (b) 10^8 N
(c) 0 N (d) 2×10^4 N

Answer: **(a) 10^4 N**

9. A bullet of mass m moving with a speed *v* strikes a wooden block of mass M & gets embedded into the block. The final speed is –:
(a) $\sqrt{\frac{M}{m+M}}V$ (b) $\sqrt{\frac{m}{M+m}}V$
(c) $\frac{Mv}{m+M}$ (d) $\frac{V}{2}$

Answer: **(c) $\frac{M}{m+M}V$**

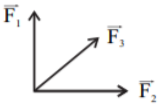
Explanation: By law of conservation of momentum

$$M v + M (0) = (m + M) V$$

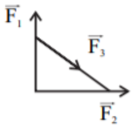
$$\Rightarrow v = \frac{Mv}{m+M}$$

10. Which of the four arrangements in the figure correctly shows the vector addition of two forces F_1 & F_2 to yield the third force F_3?

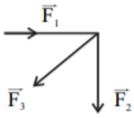
(a)



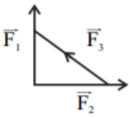
(b)



(c)



(d)



Answer: **(a)**

11. If two forces are acting at a point such that the magnitude of each force is 2N and the magnitude of their resultant is also 2N, then the angle between the two forces is

(a) 120° (b) 60°

(c) 90° (d) 0°

Answer: **(a) 120°**

Explanation: $P = Q = 2N, \; R = 2N$

$$R^2 = P^2 + Q^2 + 2PQ \cos\theta$$

$$\Rightarrow 4 = 4 + 4 + 2(4) \cos\theta$$

$$\Rightarrow \cos\theta = \frac{-4}{8} = \frac{-1}{2}$$

$$\Rightarrow \theta = 120^\circ$$

12. The dimensions of action are –:

(a) $[MLT^{-2}]$ (b) $[M^2LT^{-3}]$

(c) $[MLT^{-1}]$ (d) $[ML^2T^{-1}]$

Answer: **(a) $[MLT^{-2}]$**

Explanation: action = force $\Rightarrow [MLT^{-2}]$

13. A car when passes through a bridge exerts a force on it which is equal to:

(a) $mg + \frac{mv^2}{r}$ (b) $\frac{mv^2}{r}$

(c) $mg - \frac{mv^2}{r}$ (d) none of these

Answer: **(c) $mg - \frac{mv^2}{r}$**

14. A particle revolves round a circular path. The acceleration of the particle is inversely proportional to –:

(a) radius	(b) velocity
(c) mass of particle	(d) both (b) & (c)

Answer: **(a) radius**

Explanation: $a = \frac{v^2}{r}$ $\Rightarrow a \propto \frac{1}{r}$

15. If Maximum and minimum values of the resultant of two forces acting at a point are 7N and 3N respectively, the smaller force is equal to –:

(a) 4N	(b) 5N
(c) 3N	(d) 2N

Answer: **(d) 2N**

Explanation: $F_{\text{max.}} = P + Q = 7N$ ——— (1)

$F_{\text{min.}} = P - Q = 3N$ ——— (2)

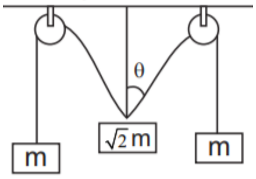
From (1) & (2)

$2P = 10\ N \Rightarrow P = 5\ N$

On putting P = 5 N in in (1): $5\ N + Q = 7\ N$

$\Rightarrow Q = 2N$

16. The pulley & strings shown in figure are smooth and of negligible mass. For the system to remain in equilibrium, the angle θ should be –:



(a) 0°	(b) 30°
(c) 45°	(d) 60°

Answer: **(c) 45°**

Explanation: For equilibrium of mass m, T = mg —— (1)

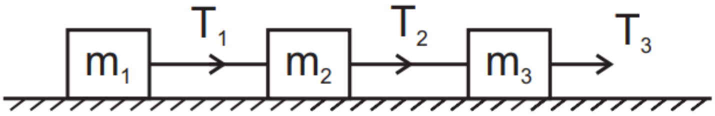
For equilibrium of mass $\sqrt{2}$ m

$2T \cos\theta = \sqrt{2}\ mg$ ——— (2)

Solve (1) & (2)

$\Rightarrow \cos\theta = \frac{1}{\sqrt{2}},\ \theta = 45°.$

17. Three block of masses m_1, m_2 & M_3 are connected by mass less stings as shown on a frictionless table.



They are pulled with a force $T_3 = 40N$, If $m_1 = 10$ kg, $m_2 = 6$ kg, & $m_3 = 4$ kg, then tension T_2 will be

(a) 20 N (b) 40 N
(c) 10 (d) 32 N

Answer: **(d) 32 N**

Explanation: net acceleration = $\frac{T_3}{m_1+m_2+m_3} = \frac{40}{20} = 2\ m/s^2$

$T_2 = (m_1 + m_2)a = 16 \times 2 = 32$ N

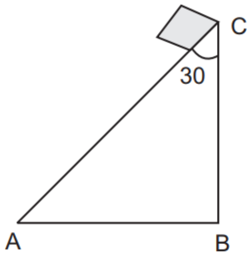
18. Three forces $\vec{A} = \hat{i} + \hat{j} - \hat{k}$, $\vec{B} = 2\hat{i} - \hat{j} + 3\hat{k}$ are acting on a body to keep it in equilibrium. Then $\vec{C}$

(a) $-(3\hat{i} + 4\hat{k})$ (b) $-(4\hat{i} + 3\hat{k})$
(c) $3\hat{i} + 4\hat{k}$ (d) $2\hat{i} + 3\hat{k}$

Answer: **(a) $-(3\hat{i} + 4\hat{k})$**

19. A body of mass M starts sliding down an Inclined plane where critical angle is < ACB = 30° as shown in figure, the coefficient of friction will be

(a) $\frac{Mg}{\sqrt{3}}$ (b) $\sqrt{3}$ mg
(c) $\sqrt{3}$ (d) None of these

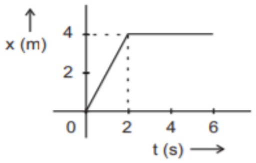


Answer: **(c) $\sqrt{3}$**

Explanation: $\mu = \tan 60° = \sqrt{3}$

20. In the figure given, the position-time graph of a particle of mass 0.1 kg is shown the impulse at t = 2s is –:

(a) 0.2 kg m/s (b) – 0.2 kg m/s
(c) 0.1 kg m/s (d) – 0.4 kg m/s



Answer: **(b) – 0.2 kg m/s**

Explanation: Impulse = change in momentum = m (v – u)= 0.1 (0 – 2)

= – 0.2 kg m/s

21. If µs, µk and µr are coefficients of static friction, kinetic friction and rolling friction, then

(a) µs < µk < µr (b) µk < µr < µs

(c) µr < µk < µs (d) µr = µk = µs

Answer: **(c) µr < µk < µ**

22. 'Net force acting on an object is found to be zero.' It can be inferred that the object

(a) May be at rest

(b) May be in uniform motion

(c) May be in uniformly accelerated motion

(d) Both a & b

Answer: **(d) Both a & b**

23. The coefficient of static friction between two surfaces depends upon

(a) the normal reaction (b) the shape of the surface in contact

(c) the area of contact (d) None of the these

Answer: **(a) the normal reaction**

24. Which of the following has the greatest inertia?

(a) A single atom (b) a molecule

(c) A one-rupee coin (d) a cricket ball

Answer: **(d) a cricket ball**

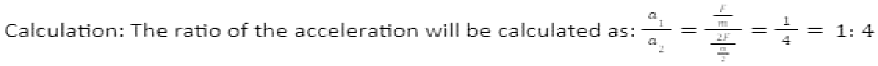
Explanation: The heavier an object is, the more difficult it is to move it or the more force is necessary to move it, resulting in a higher inertia.

25. If the force applied to a body is doubled and the mass is cut in half, What would be the accelerations' ratio?

(a) 1:2 (b) 2:1

(c) 1:4 (d) 4:1

Answer: **(c) 1:4**

Explanation: 

Calculation: The ratio of the acceleration will be calculated as: $\frac{a_1}{a_2} = \frac{\frac{F}{m}}{\frac{2F}{\frac{m}{2}}} = \frac{1}{4} = 1:4$

26. On the roof of a train travelling on horizontal rails, a simple pendulum swing. If the pendulum’s string is pointing towards the front, the train is-

(a) Moving at a steady speed (b) Moving with acceleration

(c) Moving with retardation (d) At rest

Answer: **(c) moving with retardation**

27. The quicker the momentum changes –:

(a) The force is less (b) The force is greater

(c) The force is zero (d) There is no force.

Answer: **(b)the force is greater**

28. A monkey is sitting at a spring balance that reads 60 kilograms. What effect will the monkey having jumped off the balance have on the reading?

(a) Decrease (b) No change in reading

(c) Increase (d) First increase and then becomes zero

Answer: **(d) First increase and then becomes zero**

29. A shell of mass 200 g is fired by a gun of mass 100 kg. If the muzzle speed of the shell is 80 m/s, calculate the recoil speed of the gun,

(a) 16 cm/s (b) 18 cm/s

(c) 4 cm/s (d) 16 cm/s

Answer: **(a) 16 cm/s**

30. A bullet of mass 0.04 kg moving with a speed of 90 1 ms- enters a heavy wooden block and stopped after 3s. What is the average resistive force exerted by the block on the bullet?

(a)1N (b)1.2N

(c)2N (d)3N

Answer: **(b) 1.2 N**

31. Every action has an equal and opposite reaction, which suggests that

(a) action and reaction always act on different bodies
(b) the forces of action and reaction cancel to each other
(c) the forces of action and reaction cannot cancel to each other
(d) Both (a) and (c)

Answer: (d) Both (a) and (c)

32. Inertia of an object is directly dependent on……….

(a) impulse (b)momentum
(c) mass (d)density

Answer: (c) mass

Explanation: The term inertia means resistance of any physical object. It is defined as the tendency of a body to remain in its position of rest or uniform motion. So, it is dependent on mass of the body.

33. An initially stationary device lying on a frictionless floor explodes into two pieces and slides across the floor. One piece is moving in positive x-direction then other piece is moving in –:

(a) positive y – direction (b) negative y – direction
(c) negative x – direction (d) at angle from x-direction

Answer: (c) negative x – direction

34. A hockey player is moving northward and suddenly turns westward with the same speed to avoid an opponent. The force that acts on the player is -:

(a) frictional force along westward
(b) muscle force along southward
(c) frictional force along south – west
(d) muscle force along south-west

Answer: (c) frictional force along south – west

35. A constant retarding force of 50N is applied to a body of mass 20 kg moving initially with a speed of 15 ms^{-1}. How long time does the body take to stop?

(a) 6s (b) 8s

(c) 9s (d) 10s

Answer: **(a) 6s**

Explanation: Given, F = 50N, m = 20kg, v = 15 ms^1

Impulse, F = $\frac{mv}{\Delta t}$

Time, $\Delta t = \frac{mv}{F} \Rightarrow , \ \Delta t = \frac{20 \times 15}{50}$ = 6 sec

36. A body of mass 6kg is acted on by a force so that its velocity changes from $3ms^{-1}$ to $5ms^{-1}$, then change in momentum is –:

(a) 48N-s (b) 24N-s

(c) 30N-s (d) 12N-s

Answer: **(d) 12N-s**

37. A batsman hits back at ball straight in the direction of the bowler without changing its initial speed of 12 ms^{-1}. If the mass of the ball is 0.15 kg, find the impulse imparted to the ball. (Assume linear motion of the ball)

(a) 1.8N-s (b) 3.6N-s

(c) 3.6N-m (d) 1.8N-m

Answer: **(b) 3.6N-s**

38. Three concurrent coplanar forces 1N, 2N and 3N are acting along different directions on a body can keep the body in equilibrium, if –:

(a) 2N and 3N act at right angle

(b) 1N and 2N act at acute angle

(c)1N and 2N act at right angle

(d) Cannot be possible

Answer: **(d) cannot be possible**

39. If a box is lying in the compartment of an accelerating train and box is stationary relative to the train. What force cause the acceleration of the box?

(a) Frictional force in the direction of train
(b) Frictional force in the opposite direction of train
(c) Force applied by air
(d) None of the above

Answer: **(a) Frictional force in the direction of train**

Explanation: Frictional force in the direction of train causes the acceleration of the box lying in the compartment of an accelerating train.

40. Apparent weight of a body = actual weight of the body, if the body
(a) Moves with increasing velocity
(b) Remains at rest
(c) Remains in a state of uniform motion
(d) Option (b) and (c)

Answer: **(d) Option (b) and (c)**

Explanation: Apparent weight of a body is equal to its actual weight if the body is either in a state of rest or in a state of uniform motion.

06

Work, Energy And Power

Short summary

What do we learn

Quick Revision

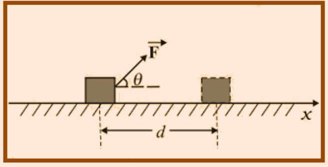
➢ Work

Work is said to be done when a force (push or pull) applied to an object causes a displacement of the object.

"The work done by a force is the product of the magnitude of force component in the direction of displacement and the displacement of this object."

➢ Vector form of work

If force F is acting at angle **θ** with respect to the displacement d of the object, its component along d will be F cos θ.



Then work done by force F is given by:

W = F cos θ. d

In vector form: **W = F.d**

- Unit of work: N × m = Joule (SI)
- Dimension: $[M^1L^2T^{-2}]$
- **1 joule:**

"1 joule is defined as the amount of work done when a force of 1 Newton displaces a body 1 meter."

➢ Positive & Negative work

Positive work: If the force is apply in same direction of displacement then work done is called positive work.

θ = 0° ⇒, W = Fd cos 0° = Fd (1) = **Fd**

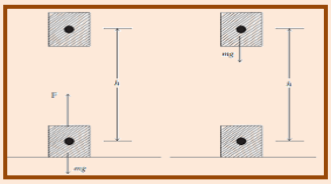
Negative work: If the force is apply in opposite direction of displacement then work done is called negative work.

θ = 180° ⇒ W = Fd cos180° = Fd (-1) = **-Fd**

(A) Work done shall be negative for θ lying between 90° and 270°.

(B) Work done is zero when θ = 90°.

➢ Work done by gravity



In Fig. A, work is done against the force mg (downwards) and the displacement is (upward) ⇒ θ = 180°

W = Fd cos180° = mgh (-1) = **-mgh**

In fig. B, mass is being lowered. *mg* and *d* are in same direction. ⇒ θ = 0°

W = Fd cos 0° = W = mgh (1) = **+mgh**

➢ Work done by a variable force

$\boxed{W = \sum \Delta W}$ $\Rightarrow$ $\boxed{W = \lim_{\Delta x \to 0} F(x)\, \Delta x}$

Example –: spring experiences variable force.

- spring will exert a force on the block given by **F = -kx** , where x is compression or elongation in spring and k is a constant called spring constant. Work done by spring force:

$$\boxed{W = -\left[\frac{1}{2}\right] k x_m^2}$$

- S.I unit of spring constant is **Nm^{-1}**.
- Value of k depends inversely on un stretched length and nature of material of spring.

➢ Power

“The rate at which work is done is called power.”

The average power is defined as:

$$\boxed{\textbf{Average power} = \frac{\text{work done}}{\text{time taken}}}$$

Mathematically, **P =** $\frac{\Delta W}{\Delta t}$

Instantaneous power is defined as:

$$\boxed{P = \text{limit}_{\Delta t \to 0} \left(\frac{\Delta W}{\Delta t}\right) = \frac{dW}{dt}}$$

- S.I. unit of power is watt.
- **1 watt** - :

“When 1 joule of work is done in 1 second then we can say that power of doing work is 1 watt.”

- Dimensional formula: **[M^{1}L^{2}T^{-3}]**

➢ Energy

“Capacity to do work is called Energy.” If a system or object has energy, it has ability to do work.

- It is also scalar quantity.
- S.I. unit of energy is also **joule.**
- C.G.S. unit of energy is ‘erg’.
- Practical units: electron volt (eV), Kilowatt hour (KWh), Calories (Cal)

- Relation between different units:

1 Joule = 10^7 erg
1 eV = 1.6×10^{-19} Joule
1 KWh = 3.6×10^6 Joule
1 Calorie = 4.18 Joule

➢ Types of energy

There are two types of mechanical Energy:

① Kinetic energy
② Potential energy

➢ Kinetic energy

“The energy possessed by a body by virtue of its motion is called kinetic energy.”

Let m = mass of the body, v = velocity of the body then $\boxed{\text{K.E.} = \frac{1}{2} mv^2}$

Work-energy theorem: It states that work done by a force acting on a body is equal to the change produced in the kinetic energy of the body. $\boxed{W = k_f - k_i}$

➢ Potential energy

"Objects possess another kind of energy due to their position in space. This energy is known as Potential Energy."

P.E. Or **U = mgh**

➢ Types of potential energy

① Gravitational potential energy
② Elastic potential energy

➢ Gravitational potential energy

Gravitational potential energy of a body is the energy possessed by the body by virtue of its position above the surface of the earth.

- It is given by $\boxed{U = mgh}$

where m = mass of a body
g = acceleration due to gravity
h = height through which the body is raised.

➢ Elastic potential energy

When an elastic body is displaced from its equilibrium position, work is needed to be done against the restoring elastic force. The work done is stored up in the body in the form of its elastic potential energy.

- It is given by $\boxed{U = \frac{1}{2}kx^2}$

Where, k = spring constant

➢ Law of Conservation of energy

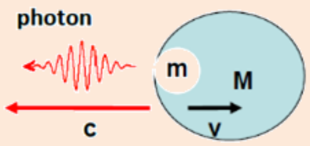
According to the law of conservation of energy, the total energy of an isolated system does not change. Energy may be transformed from one form to another but the total energy of isolated system remains constant.

"Energy can neither be created, nor destroyed." $\boxed{U_1 + K_1 = U_2 + K_2}$

- Besides mechanical energy, the energy may manifest itself in many other forms. Some of these forms are: thermal energy, electrical energy, chemical energy, visual light energy, nuclear energy etc.

➢ Equivalence of mass and energy

According to Einstein, mass and energy are inter-convertible. That is, mass can be converted into energy and energy can be converted into mass.



m = mass transformed to photon energy

M = remained mass

c = speed of light

v = speed of M

E = Energy generated by the transformation of 'm' mass to photon

➢ Collisions

Collision is defined as an isolated event in which two or more colliding bodies exert relatively strong forces on each other for a relatively short time.

Collision between particles has been divided broadly into two types.

(i) Elastic collisions

(ii) Inelastic collisions

➢ Elastic Collisions

In a collision if both the linear momentum and the kinetic energy of the system remain conserved, that is called elastic collision.

Example: Collisions between atomic particles, atoms, marble balls and billiard balls.

➢ Inelastic Collisions

A collision is said to be inelastic if the linear momentum of the system remains conserved but its kinetic energy is not conserved.

Example: When we drop a ball of wet putty on to the floor then the collision between ball and floor is an inelastic collision.

➢ Conservative force

If the work done by or against force is dependent only on initial and final position of the body and not on the path followed by body, then this type of force is called **Conservative force.**

- Examples of conservative force –:
  - – Gravitational force
  - – Magnetic force
  - – Electrostatic force etc.

NOTE: Work done by the conservative force in a closed path is zero.

➢ Non – Conservative force

If the work done by or against force is dependent on the path followed by body ,then this type of force is called **Non – conservative force.**

- Examples of conservative force –:

– Friction force

– Viscous force

– Induction force in cyclotron etc.

NOTE: Work done by the conservative force in a closed path is not zero.

MCQs

1. A mass of 5 kg is moving along a circular path of radius 1 m. If the mass moves with 300 rev/min. it's kinetic energy would be:

(a) $250\ \pi^2$ (b) $100\ \pi^2$

(c) $5\ \pi^2$ (d) 0

Answer: **(a) $250\ \pi^2$**

Explanation: $V = \omega R, \quad \omega = \frac{2\pi}{T} = 10\pi$ rad/s

$V = 10\pi\ (1)\ ms^{-1} = 10\pi\ ms^{-1}$

$K.E. = \frac{1}{2} mV^2 = \frac{1}{2} \times 5 \times V^2 = 250\ \pi^2\ J$

2. A man is squatting on the ground gets straight up and stand. The force of reaction of ground on the man during the process is

(a) constant and equal to 'mg' in magnitude.

(b) constant and greater than 'mg' in magnitude.

(c) variable but always greater than 'mg'

(d) at first greater than 'mg' and later becomes equal to 'mg'

Answer: **(d) at first greater than 'mg' and later becomes equal to 'mg'**

Explanation: In squatting, he is tilted somewhat, hence also has to balance frictional force besides his weight in this case R = friction + mg $\Rightarrow$ R > mg
When he set straight up in that case, R = mg.

3. A body of mass 0.5 kg travels in straight line with velocity $V = ax^{3/2}$ where $a = 5\ m^{-½}\ s^{-1}$. The work done by the net force during it's displacement from x = 0 to x = 2m is

(a) 15 J (b) 50 J

(c) 10 J (d) 100 j

Answer: (b) 50 J

4. An Athlete in the Olympic games covers a distance of 100 m in 10s, this kinetic energy can be estimated to be in the range (assume m = 60 kg)

(a) 200J – 500 J (b) 2×10^5J – 3×10^5J

(c) 20000J – 50000J (d) 2000J – 5000J

Answer: **(d) 2000J – 5000J**

Explanation: $V_{av} = \frac{S}{t} = 10\ ms^{-1}$, m = 60 kg $\Rightarrow$ Av. K.E. 3000 J

5. A block of mass 0.5 kg is moving with a speed of 2m/s on a smooth surface. It strikes another mass of 1 kg at rest and then they move together as a single body. The energy loss during the collision is

(a) 0.16J	(b) 1.00 J
(c) 0.67 J	(d) 0.34J

Answer: (c) 0.67 J

6. A bullet fired in to a fixed target losses half of it's velocity after penetrating distance of 3 cm. How much further it will penetrate before coming to rest assuming that if faces constant resistance to it's motion?

(a) 3 cm	(b) 2.0 cm
(c) 1.5 cm	(d) 1.0 cm

Answer: (d) 1.0 cm

7. A uniform chain of length 2m is kept on a table such that a length of 60 cm hangs freely from the edge of the table. The total mass of the chain is 4 kg. What is the work done in pulling the entire chain on the table?

(a) 7.2 J	(b) 3.6 J
(c) 120 J	(d) 1200 J

Answer: (b) 3.6 J

Explanation: Mass per unit length = $\frac{4\ \text{kg}}{2\ \text{m}}$ = 2 kg m^{-1}

Mass of 60 cm length = 1.2 kg
Weight of hanging part = 1.2 × 10 = 12N
W = F × S = 12 × 0.3 = 3.6 J.

8. If the linear momentum is increased by 50%, then kinetic energy will increase by

(a) 50%	(b) 100%
(c) 125%	(d) 25%

Answer: (c) 125%

9. A block having mass 'm' collides with another stationary block having mass 2m. The lighter block comes to rest after collision. If the velocity of first block is V, than the value of co-efficient of restitution will be:

(a) 0.5 (b) 0.4
(c) 0.6 (d) 0.8

Answer: (a) 0.5

10. A body of mass 50 kg is at rest. The work done to accelerate it by 20 m/s in 10 s is:

(a) 10^3 J (b) 10^4 J
(c) 2×10^3 J (d) 4×10^4 J

Answer: (b) 10^4 J

Explanation: $a = \frac{v-u}{t} = 2\ ms^{-2}$, $S = ut + \frac{1}{2}at^2 = 100$ m
$W = F \times S = 10^4$ J

11. A spring of force constant 800 Nm–1 has an extension of 5 cm. The work done in extending it from 5 cm to 15 cm is

(a) 16 J (b) 8 J
(c) 35 J (d) 24 J

Answer: (b) 8 J

Explanation: $W = \frac{1}{2} \times 800\ (0.15^2 - 0.05^2) = 8$ J

12. A particle is projected at an angle of 60° to the horizontal with a kinetic energy E. The kinetic energy at the highest point is

(a) E (b) E/4
(c) E/2 (d) Zero

Answer: (b) E/4

Explanation: K.E. at highest point = $\frac{1}{2}$ m $(4\cos 60°)^2$ = E/4

13. A child is sitting on a swing. Its minimum and maximum heights from the ground 0.75 m and 2 m respectively, it's maximum speed will be

(a) 10 m s^{-1} (b) 5 m s^{-1}
(c) 8 m s^{-1} (d) 15 m s^{-1}

Answer: (b) 5 m s^{-1}

Explanation: Maximum K.E. = Drop in P.E.
$\frac{1}{2} m V_{max}^2 = mg (h_2 - h_1) \Rightarrow V_{max} = 5\ ms^{-1}$

14. 300 J of work is done in sliding a 2 kg block up on inclined plane of height 10 m. Work done against friction is (g = 10 ms^{-2})

(a) 1000 J	(b) 200 J
(c) 100 J	(d) Zero

Answer: **(c) 100 J**

Explanation: Total work done = Gain in P.E.+ Work done against friction

$300 = 2 \times 10 \times 10 + W \Rightarrow W = 100$ J.

15. During inelastic collision between two bodies, which of the following quantities always remain conserved

(a) Total kinetic energy	(b) Total mechanical energy
(c) Total linear momentum	(d) Speed of each body

Answer: **(c) Total linear momentum**

16. Two bodies with kinetic energies in the ratio 4:1 are moving with equal linear momentum. The ratio of their masses is

(a) 4 : 1	(b) 1 : 1
(c) 1 : 2	(d) 1 : 4

Answer: **(d) 1:4**

17. Which of the following is not a conservative force?

(a) Gravitational force	(b) Frictional force
(c) Spring force	(d) None of these

Answer: **(b) Frictional force**

Explanation: As work done by frictional force over a closed path is not zero, therefore, it is non-conservative force.

18. A position dependent force, $F = 7 - 2x + 3x^2$ N acts on a small body of mass 2 kg and displaces it from x = 0 to x = 5 m. The work done in joule is:

(a) 135	(b) 270
(c) 35	(d) 70

Answer: **(a) 135**

19. A ball is dropped from height 'h' on the ground where co-efficient of restitution is 'e'. After one bounce the maximum height is

(a) e^2h (b) $e\sqrt{h}$

(c) eh (d) $\sqrt{eh}$

Answer: (a) e^2h

20. How much water a pump of 2 KW can raise in one minute to a height of 10 m? (g = 10 ms)

(a) 1000 liters (b) 1200 liters

(c) 10 liters (d) 2000 liters

Answer: (b) 1200 liters

Explanation: $P = \frac{W}{t} \Rightarrow W = Pt = mgh \Rightarrow m = 1200$ kg

21. Four particles given, have same momentum. Which has maximum kinetic energy?

(a) Proton (b) Electron

(c) Deutron (d) Alpha-particles

Answer: (b) Electron

22. A bomb of mass 30 kg at rest explodes in to two pieces of masses 18 kg and 12 kg. The velocity of 18 kg mass is 6 ms^{-1}. The kinetic energy of the other mass is

(a) 324 J (b) 486 J

(c) 256 J (d) 5245 J

Answer: (b) 486 J

Explanation: By conservation of momentum

$30 \times 0 = 18 \times 6 + 12 + V \rightarrow V = -9\ ms^{-1}$

$K.E. = \frac{1}{2} mV^2 = 486$ J

23. If a light body and heavy body have same kinetic energy, then which one has greater linear momentum?

(a) Lighter body (b) Heavier body

(c) Both have same momentum (d) Can't be predicted

Answer: (b) Heavier body

24. What is the power utilized when work of 1000 J is done in 2 seconds?

(a) 100 W	(b) 200 W
(c) 20 W	(d) 500 W

Answer: **(d) 500 W**

Explanation: W = 1000J, t = 2 seconds

Power = work/time = 1000/2 = 500 W

25. Work is always done on a body when

(a) a force acts on it

(b) it moves through a certain distance

(c) it experiences an increase in energy through a mechanical influence

(d) None of these

Answer: **(c) it experiences an increase in energy through a mechanical influence**

26. In which of the following work is being not done?

(a) Shopping in the supermarket

(b) Standing with a basket of fruit on the head

(c) Climbing a tree

(d) Pushing a wheel barrow

Answer: **(b) Standing with a basket of fruit on the head**

27. A wooden cube having mass 10 kg is dropped from the top of a building. After 1 s, a bullet of mass 20 g fired at it from the ground hits the block with a velocity of 1000 m / s at an angle of 30 to the horizontal moving upwards and gets imbedded in the block. The velocity of the block/bullet system immediately after the collision is

(a) 17 m/ s	(b) 27 m/s
(c) 52 m / s	(d) 10 m/s

Answer: **(a) 17 m/ s**

28. An electric heater of rating 1000 W is used for 5 hrs per day for 20 days. What is the electrical energy utilized?

(a) 100 kWh (b) 200 kWh
(c) 120 kWh (d) 500 kWh

Answer: **(a) 100 kWh**

Explanation: The power of the electric heater is 1000 W, and the time period is 20 × 5 = 100 hr.

Electrical energy = Power × Time

Electrical energy = 1000 × 100 = 100000 Wh

Electrical energy = 100 kWh

29. The temperature at the bottom of a high water fall is higher than that at the top because

(a) by itself heat flows from higher to lower temperature
(b) the difference in height causes a difference in pressure
(c) thermal energy is transformed into mechanical energy
(d) mechanical energy is transformed into thermal energy.

Answer: **(b) the difference in height causes a difference in pressure**

30. A ball moves in a frictionless inclined table without slipping. The work done by the table surface on the ball is:

(a) Negative (b) Zero
(c)Positive (d) None of the options

Answer: **(b) Zero**

Explanation: The work done by a ball when it moves on a frictionless inclined table without slipping is zero.

31. A bullet fired into a fixed target loses half of its velocity after penetrating 3 cm. How much further will it penetrate before coming to rest assuming that it faces constant resistance to motion?

(a) 2.0 cm (b) 3.0 cm
(c) 1.0 cm (d) 1.5 cm

Answer: **(c) 1.0 cm**

32. When the force retards the motion of body, the work done is

(a) zero (b) negative
(c) positive (d) none of these

Answer: **(b) negative**

33. The coefficient of restitution e for a perfectly inelastic collision is

(a) 1 (b) 0
(c) infinity (d) –1

Answer: **(b) 0**

Explanation: For a perfectly inelastic collision, e = 0.

34. If two particles are brought near one another, the potential energy of the system will

(a) increase (b) decrease
(c) remains the same (d) equal to the K.E

Answer: **(a) increase**

35. If the speed of an object is doubled, how does its kinetic energy change?

(a) It becomes half (b) It remains the same
(c) It becomes double (d) It becomes quadruple

Answer: **(c) It becomes double**

36. In an inelastic collision

(a) momentum is not conserved
(b) momentum is conserved but kinetic energy is not conserved
(c) both momentum and kinetic energy are conserved
(d) neither momentum nor kinetic energy is conserved

Answer: **(b) Momentum is conserved but kinetic energy is not conserved.**

37. In an elastic collision, what is conserved?

(a) Kinetic energy (b) Momentum
(c) Both (a) and (b) (d) Neither (a) nor (b)

Answer: (c) Both (a) and (b)

38. No work is done if

(a) displacement is zero (b) force is zero

(c) force and displacement are mutually perpendicular

(d) All of these

Answer: (d) All of these

39. A force → $\vec{F} = -K(y\,\hat{i} + x\,\hat{j})$ (where K is a positive constant) acts on a particle moving in the xy plane. Starting from the origin, the particle is taken along the positive x – axis to the point (a, 0) and then parallel to the y – axis to the point (a, a). The total work done by the force F on the particle is:

(a) $-2Ka^2$ (b) $2Ka^2$

(c) $-Ka^2$ (d) Ka^2

Answer: (c) $-Ka^2$

40. The magnitude of work done by a force

(a) depends on frame of reference

(b) does not depend on frame of reference

(c) cannot be calculated in non-inertial frames.

(d) both (a) and (b)

Answer: (d) both (a) and (b)

41. A force $\vec{F} = (5\hat{i} + 3\,\hat{j} + 2\hat{k})$ N is applied over a particle which displaces it from its origin to the point $\vec{r} = (2\hat{i} - \hat{j})$ m . The work done on the particle in joules is

(a) - 7 (b) 7

(c) 10 (d) 13

Answer: (b) 7

42. The work energy theorem states that:

(A) Work done on an object is equal to its mass times acceleration

(b) Work done on an object is equal to the change in its kinetic energy

(c) Work done on an object is equal to its potential energy

(d) Work done on an object is independent of its velocity

Answer: (b). Work done on an object is equal to the change in its kinetic energy

43. What happens to the velocity of objects involved in a completely inelastic collision?

(a) They move apart after the collision.

(b) They stick together and move with a common velocity after the collision.

(c) They bounce off each other after the collision.

(d) Their velocities remain unchanged after the collision.

Answer: (b) They stick together and move with a common velocity after the collision.

44. If a moving object collides elastically with a stationary object of the same mass, what is the result?

(a) The stationary object gains all the momentum of the moving object.

(b) Both objects come to rest after the collision.

(c) The moving object continues with its initial velocity, and the stationary object moves with double the initial velocity of the moving object.

(d) Both objects move with half the initial velocity of the moving object after the collision.

Answer: (c) The moving object continues with its initial velocity, and the stationary object moves with double the initial velocity of the moving object.

45. When is momentum conserved in a collision?

(a) Only in perfectly elastic collisions.

(b) Only in perfectly inelastic collisions.

(c) In both perfectly elastic and perfectly inelastic collisions.

(d) Momentum is never conserved in collisions.

Answer: (c) In both perfectly elastic and perfectly inelastic collisions.

46. Work done by a conservative force is equal to:

(a) Force times distance

(b) Change in kinetic energy of an object

(c) Negative of the change in potential energy of an object

(d) Force times velocity

Answer: (c) Negative of the change in potential energy of an object

47. If an object is moved on a closed loop and the net work done by all the forces is zero, then:

(a) The only force acting on the object is conservative.

(b) The only force acting on the object is non-conservative.

(c) The object is not moving.

(d) The object is moving at a constant velocity.

Answer: (a) The only force acting on the object is conservative.

48. Which of the following forces is conservative in nature?

(a) Frictional force (b) Tension force in a rope

(c) Magnetic force (d) Normal force

Answer: (b) Tension force in a rope

49. When a ball is thrown vertically upwards, which of the following forces does work on it?

(a) Gravity (b) Both gravity and air resistance

(c) Air resistance (d) Neither gravity nor air resistance

Answer: (c) Air resistance

50. If a car moves in a complete circle at a constant speed, the work done by gravitational force is:

(a) Positive (b) Negative

(c) Zero (d) Variable

Answer: (c) Zero

09

Properties of fluids

Short summary

What do we learn

Quick Revision

➢ Fluids

Liquids and gases have a property to flow. Hence the liquids and gases are collectively called **FLUIDS**.

➢ Properties of fluids

Hydrostatic pressure, buoyancy, surface tension, viscosity and some very important laws given by great physicist such as Pascal's law, Archimedes principle, Bernoulli's principle, strokes law etc.

➢ Thrust of liquid

"The total force exerted by a liquid on any surface in contact with it is called thrust."

➢ Pressure

"Effect of force on unit area is called pressure."

Or,

Normal force or thrust per unit area exerted by fluid is called pressure.

$$\boxed{P = \frac{Thrust}{Area}} \quad \text{OR} \quad \boxed{P = \frac{Force}{Area}}$$

➢ Hydrostatic pressure

The pressure exerted by a fluid at rest is called hydrostatic pressure.

- Pressure is a scalar quantity.
- Dimensional formula is $[M^1L^{-1}T^{-2}]$.
- S.I. Unit of pressure is Nm^{-2} and is called Pascal (Pa).

➢ Pressure at a point inside the cylinder

- If the cylinder is in equilibrium the resultant force is zero.
- the pressure P at the bottom of a column of liquid of height *h* is given by:

$$\boxed{P = \rho g h}$$

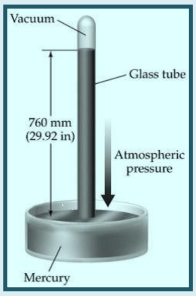
➢ Atmospheric pressure

"The pressure of atmosphere of the earth is termed as Atmospheric pressure."

- Normal atmospheric pressure at sea level (an average value) is **1.013×10^5 Pa**.

➢ *Mercury barometer*

A mercury barometer is an instrument used to measure atmospheric pressure. It operates on the principle that atmospheric pressure can support a column of mercury in a vacuum.



- **Components**
  - Glass Tube
  - Mercury Reservoir
- **Working Principle**
  - Filling the Barometer
  - Balancing Atmospheric Pressure
  - Reading the Pressure
- Atmospheric pressure is measured in millimeters of mercury (mmHg) or inches of mercury (in Hg).

Applications: Mercury barometers are used in weather forecasting, aviation, and scientific research.

➢ *Buoyancy*

"Buoyancy is the tendency of an object to float in a fluid."

- All liquids and gases in the presence of gravity exert an upward force known as Buoyant Force.
- Buoyant force is affected due to density, volume & acceleration due to gravity.

➢ *Archimedes principle*

"When an object is submerged partially or fully in a fluid, the magnitude of the buoyant force on it is always equal to the weight of the fluid displaced by the object."

- A body is said to float in a liquid when the average density of the body is less than that of the liquid.
- The weight of the liquid displaced by the immersed part of the body should be the same as the weight of the body.
- The center of gravity of the body and center of buoyancy should be along the same vertical line.

➢ *Pascal's law*

Pascal's law can be explained simply as –:

"If we apply pressure at any point on a container which is filled with liquid , then pressure will be equally distributed at all points inside the liquid and as well as wall of container".

$$\boxed{P = P_1 = P_2 = P_3} \quad \& \quad \boxed{\frac{F_1}{A_1} = \frac{F_2}{A_2}}$$

➢ *Applications of Pascal's law*

1. Hydraulic Press/Balance/Jack/Lift
2. Hydraulic Jack or Car Lifts
3. Hydraulic Brakes

➢ *Surface tension*

- Surface tension is the property by virtue of which the free surface of a liquid at the rest behaves like elastic to occupy minimum surface area.

It is a property of the liquid surface due to which it has tendency to decrease its surface area.

- The surface tension of a liquid can be defined as "the force per unit length in the plane of liquid surface".

$$\boxed{T = \frac{F}{L}}$$

- S.I. unit of surface tension is Nm^{-1}.
- Dimensional formula is $[MT^{-2}]$.
- It is a scalar quantity.

➢ *Intermolecular force*

The force between the molecules of matter is termed as Intermolecular force.

There are two types of it as follows –:

① *Cohesive force*

The force of attraction between the molecules of same substance is called cohesive force.

Ex. –: $H_2O – H_2O$ and $Hg – Hg$

② *Adhesive force*

The force of attraction between the molecules of different substances is called adhesive force.

Ex. -: $H_2O – SiO_2$ and $H_2O – Hg$

➢ *Surface energy*

"The work done to increase the surface area of the liquid is termed as surface energy."

$$\boxed{W = T \times A}$$

• This work done by the external force is stored as the potential energy of the new surface and is called as surface energy.

• Here, a new formula is derived for surface tension (T).

$$\boxed{T = \frac{W}{A}}$$

➢ *Applications of surface tension*

1. Mosquitoes sitting on water.
2. Excess pressure on concave side of a spherical surface.
3. Detergents and surface tension.
4. Wax – duck floating on water.

➢ *Angle of contact*

Angle of contact is defined as "the angle between the tangent to the liquid surface and the wall of the container at the point of contact as measured from within the liquid."

• Angle of contact depends on –:

- Temperature
- Pair of solid and liquid

➢ *Capillary action*

Capillary tube: A tube which is very fine bore (hair like), or its cross – sectional area is very small, is termed as 'Capillary tube'.

Capillary action: Phenomenon of the elevation or depression of a liquid in a capillary tube is basically due to surface tension and is known as 'Capillary action' or 'capillarity'.

- If the radius of tube is less (in a very fine bore capillary), liquid rise will be high.

- The liquid surface in a capillary tube is either concave or convex. This curvature is due to surface tension. The rise in capillary is given by

$$\boxed{h = \frac{2T\cos\theta}{rdg}}$$

➢ *Viscosity*

"The property of a fluid by virtue of which it opposes the relative motion in its adjacent layers is known as viscosity."

➢ *Examples of Viscosity*

1. When we swim in a pool of water, we experience some resistance to our motion, this is due to viscous force of motion of water.
2. The cloud particles fall down very slowly account of viscosity of air and hence seeing floating in sky.

➢ *Velocity gradient*

The velocity changes by *dv* in going through a distance *dx* perpendicular to surface. The quantity *dv/dx* is called the **velocity gradient**.

$$\boxed{\text{Velocity gradient} = \frac{dv}{dx}}$$

The viscous force F between two layers of the fluid is proportional to area (A) and velocity gradient.

$$F \propto A\frac{dv}{dx} \Rightarrow \boxed{F = -\eta A\,(dv/dx)}$$

➢ *Coefficient of viscosity*

The constant of proportionality η is called coefficient of viscosity.

➢ *Streamline flow*

When a fluid flows such that each particle of the liquid passing a given point moves along the same path and the same velocity as its perpendicular, the flow is called '*Streamline flow*'.

➢ *Laminar flow*

If a liquid is flowing a horizontal surface with a steady flow and moves in the form of layers of different velocities which do not mix with each other, then the flow of liquid is called '*laminar flow*'.

➢ *Turbulent flow*

When a liquid moves with a velocity greater than its critical velocity, the motion of the particles of liquid becomes disordered or irregular. Such a flow is called a turbulent flow.

➢ *Critical velocity*

The critical velocity is that velocity of liquid flow up to which its flow is streamlined and above which its flow becomes turbulent.

The value of critical velocity of any liquid depends on the:

- coefficient of viscosity (η) of the liquid
- diameter of the tube (d) through which the liquid flows
- density of the liquid (ρ)

Therefore, $\boxed{v_c = R.\frac{\eta}{\rho}}$

Where *R* is constant of proportionality and is called **Reynolds's Number**. It has no dimensions.

➢ *Equation of continuity*

For an incompressible, streamlined and non-viscous liquid product of area of cross section of tube and velocity of liquid remains constant.

$$\boxed{A_1V_1 = A_2V_2}$$

This expression is called "Equation of continuity".

➢ *Stokes' law*

Stokes' law states that tangential backward viscous force acting on a spherical mass of radius r falling with velocity 'v' in a liquid of coefficient of viscosity η is given by

$$\boxed{F = 6\pi\,\eta\,r\,v}$$

➢ *Terminal velocity*

"Terminal velocity is defined as the highest velocity attained by an object falling through a fluid."

$$\boxed{V_0 = \frac{2\,r^2\,(\rho-\sigma)g}{9\eta}}$$

➢ *Bernoulli's principle*

Bernoulli's Principle states that "where the velocity of a fluid is high, the pressure is low and where the velocity of the fluid is low, pressure is high."

➢ *Bernoulli's theorem*

According to this theorem the total energy (pressure energy, potential energy and kinetic energy) per unit volume or mass of an incompressible and non-viscous fluid in steady flow through a pipe remains constant throughout the flow.
It is expressed mathematically as:

$$\boxed{P + \frac{1}{2}\,\rho v^2 + \rho gh = \text{constant}}$$

Question – Answer

∗ Very short answer questions

1. What is pressure?

Answer: Pressure is defined as force per unit area and is measured in Pascal.

2. What causes pressure in a fluid?

Answer: Pressure in a fluid is caused by the collisions of its molecules with the walls of the container.

3. Define hydrostatic pressure.

Answer: Hydrostatic pressure is the pressure exerted by a fluid at rest due to the force of gravity acting on the fluid.

4. What is the equation for hydrostatic pressure?

Answer: $P = P_0 + \rho gh$ where P is the hydrostatic pressure, P_0 is the atmospheric pressure, ρ is the density of the fluid, g is the acceleration due to gravity, and h is the depth of the fluid.

5. How does hydrostatic pressure change with depth in a fluid?

Answer: Hydrostatic pressure increases with depth in a fluid due to the increasing weight of the fluid above the given depth.

6. What is Pascal's law?

Answer: Pascal's law states that in a confined fluid at rest, any change in pressure applied at any point in the fluid is transmitted undiminished throughout the fluid in all directions.

7. What is atmospheric pressure at sea level?

Answer: Atmospheric pressure at sea level is approximately 101.3 k Pa or 1 atmosphere (atm).

8. **What is a mercury barometer?**

Answer: A mercury barometer is a device used to measure atmospheric pressure by balancing the weight of a column of mercury against the atmospheric pressure.

9. **Why is mercury used in barometers instead of water?**

Answer: Mercury is used in barometers because it has a high density, allowing for a reasonably sized column in the barometer, making it sensitive to atmospheric pressure changes.

10. **Define buoyancy.**

Answer: Buoyancy is the upward force exerted by a fluid on an object placed in it, counteracting the weight of the object and allowing it to float or experience an apparent loss of weight.

11. **What determines the buoyant force acting on an object submerged in a fluid?**

Answer: The buoyant force is equal to the weight of the fluid displaced by the submerged object and depends on the volume of the object submerged.

12. **State Archimedes' Principle.**

Answer: Archimedes' Principle states that a body submerged in a fluid experiences an upward buoyant force equal to the weight of the fluid it displaces.

13. **When does an object float in a fluid?**

Answer: An object floats in a fluid when its density is less than the density of the fluid, causing the buoyant force to be greater than the object's weight.

14. **What happens to the apparent weight of an object when it is submerged in a fluid?**

Answer: The apparent weight of an object submerged in a fluid decreases due to the buoyant force acting in the upward direction, reducing the net weight experienced by the object.

15. Define surface energy.

Answer: Surface energy is the energy required to increase the surface area of a liquid by a unit amount. It is also the work done to increase the surface area.

16. What causes surface tension in a liquid?

Answer: Surface tension is caused by the cohesive forces between molecules at the surface of a liquid, pulling them inward and creating a 'skin' on the surface.

17. Which of the following has more excess of pressure - An air bubble in water of radius 1cm, surface tension of water being 727 × 10^{-3} Nm^{-1} or a soap bubble in air of radius 4cm, surface tension of soap solution being 25 × 10^{-3} Nm^{-1}. [PYQ NIOS , Jan 2021]

Answer: For air bubble in water

$$P = \frac{2T}{r} = \frac{2\times727\times10^{-3}}{2\times10^{-2}} = 72.7 \text{ N m}^{-2}.$$

For soap bubble in air

$$P' = \frac{4T'}{r'} = \frac{4\times25\times10^{-3}}{4\times10^{-2}} = 2.5 \text{ N m}^{-2}.$$

Hence, an air bubble has more excess of pressure.

18. Differentiate between cohesive and adhesive forces.

Answer: Cohesive forces are the intermolecular forces between similar molecules within a substance, while adhesive forces are the forces between different molecules of different substances.

19. Give example of cohesive force and adhesive force separately.

Answer: Water droplets forming on a leaf due to the cohesive forces between water molecules. Water sticking to the surface of a glass due to adhesive forces between water molecules and glass molecules.

20. How does soap reduce surface tension?

Answer: Soap molecules have a hydrophilic (water-attracting) and a hydrophobic (water-repelling) end. When added to water, they disrupt the cohesive forces between water molecules, reducing surface tension.

21. How does surface tension affect capillary action?

Answer: Surface tension pulls the liquid upward along the walls of a narrow tube, aiding capillary action.

22. Give an example of capillary action in plants.

Answer: Capillary action helps water move upward from the roots to the leaves in plants, providing nutrients to the entire plant.

23. What is the application of surface tension in the formation of droplets?

Answer: Surface tension allows liquids to form spherical droplets, which is essential in raindrop formation and various industrial processes like inkjet printing.

24. How is surface tension used in the creation of soap bubbles?

Answer: Surface tension in soap films forms bubbles by minimizing the surface area, allowing soap bubbles to hold their shape.

25. What is viscosity? Give an example of a viscous liquid.

Answer: Viscosity is a measure of a fluid's resistance to flow. It quantifies how easily a fluid can deform or flow. Honey is an example of a viscous liquid due to its high resistance to flow.

26. What is critical velocity?

Answer: Critical velocity is the minimum velocity required for a liquid to flow steadily without turbulence through a pipeline.

27. State the equation of continuity.

Answer: The equation of continuity states that the product of the cross – sectional area and velocity of a fluid remains constant in a continuous flow.

28. What is stokes' law ?

Answer: Stokes' law states that the viscous drag force experienced by a small spherical object moving through a viscous fluid is proportional to its velocity and radius.

29. Give an application of Stokes' law.

Answer: Stokes' law is used to determine the viscosity of fluids and is also applied in the study of sedimentation rates.

30. What is Bernoulli's principle?

Answer: Bernoulli's principle states that as the speed of a fluid increases, its pressure decreases, and vice versa, when the flow is continuous and the fluid is incompressible.

31. Give an application of Bernoulli's principle.

Answer: An airplane's lift is generated based on Bernoulli's principle. Faster air over the curved wing creates lower pressure, allowing the airplane to lift off the ground.

Short Answer Questions

32. Explain why (a) The blood pressure in humans is greater at the feet than at the brain. (b) Atmospheric pressure at the height of about 6 km decreases to nearly half of its value at sea level, though the height of the atmosphere is more than 100 km. (c) Hydrostatic pressure is a scalar quantity even though the pressure is force divided by area.

Answer: (a).The blood column to the feet is at a greater height than the head. Thus, the blood pressure in the feet is greater than that in the brain.

(b) The density of the atmosphere does not decrease linearly with the increase in altitude, in fact, most of the air molecules are close to the surface. Thus, there is this nonlinear variation of atmospheric pressure.

(c) In hydrostatic pressure, the force is transmitted equally in all directions in the liquid; thus, there is no fixed direction of pressure, making it a scalar quantity.

33. How does hydrostatic pressure enable the functioning of a hydraulic lift?

Answer: In a hydraulic lift, applying a small force to a small piston generates pressure in the fluid. This pressure, transmitted equally in all directions, moves a larger piston, exerting a much greater force. The principle behind this amplification of force is Pascal's law, based on hydrostatic pressure transmission.

34. Why does hydrostatic pressure increase with depth in a fluid?

Answer: Hydrostatic pressure increases with depth because the weight of the fluid above a certain point creates pressure. Deeper levels have more fluid above, resulting in a higher weight and, consequently, higher hydrostatic pressure at greater depths.

35. Explain Pascal's Law and its significance in hydraulic systems.

Answer: Pascal's Law states that any change in pressure applied to an enclosed fluid is transmitted undiminished in all directions. This principle is fundamental in hydraulic systems, allowing a small force applied at one point to be transmitted and amplified as a larger force at another point in the system.

36. Two pistons of a hydraulic press have diameter of 30.0 cm and 2.5 cm. Find the force exerted on the longer piston when 50.0 kg. wt. is placed on smaller piston. **[PYQ NIOS Oct 2022]**

Answer: As in hydraulic press, pressure will be equally transferred

$$\Rightarrow P_1 = P_2$$

$$\Rightarrow 50 \times g \times A_1 = m \times g \times A_2$$

$$\Rightarrow 50\,(1.25)^2 \times \pi = m\,(15)^2 \times \pi$$

$$\Rightarrow m = 7200\text{kg}$$

So, 7200kg weight should be put on a larger piston.

37. On what factors does the critical velocity of the liquid depend?

Answer: critical velocity (v_c) of liquid is:

1. Diretly proportional to the coefficient of viscosity of liquid, i.e. $v_c \propto \eta$.
2. Inversely proportional to the density of liquid, i.e. $v_c \propto \frac{1}{\rho}$.
3. Inversely proportional to the diameter of the tube through which it flows, i.e. $v_c \propto \frac{1}{D}$.

38. How does buoyancy work, and what factors affect the buoyant force experienced by an object submerged in a fluid?

Answer: Buoyancy is the upward force exerted on an object submerged in a fluid, counteracting the force of gravity. The buoyant force depends on the density of the fluid, the volume of the displaced fluid, and the acceleration due to gravity. An object will float if its density is less than the density of the fluid it is placed in.

39. A barometer reads 760 mm Hg at sea level. If the barometer is taken to the top of a mountain at an altitude where the atmospheric pressure is 650 mm Hg, calculate the height of the mountain. (Density of mercury = 13.6 g/cm^3)

Answer:

Using the barometric formula, the height of the mountain can be calculated as $h = \frac{P_0 - P}{\rho \times g}$, where P_0 and P are atmospheric pressures at sea level and mountain respectively, ρ is the density of mercury, and g is acceleration due to gravity.

Substituting the values, $\mathrm{h} = \frac{(760-650)}{13.6 \times 9.8} = 7.89\ \mathrm{km}$

40. A hydraulic lift has a small piston with an area of 0.02 m^2 connected to a larger piston with an area of 0.1 m^2. If a force of 2000 N is applied to the small piston, calculate the pressure exerted on the larger piston. (According to Pascal's law)

Answer: Using Pascal's law $F_1/A_1 = F_2/A_2$, where F_1 and A_1 are the force and area of the small piston, and F_2 and A_2 are the force and area of the large piston.

Given → $A_1 = 0.02\ m^2$, $A_2 = 0.1\ m^2$, $F_1 = 2000$ N

Solving for P_2, the pressure on the larger piston, $P_2 = \frac{F_1}{A_1} \times A_2$

$$\Rightarrow P_2 = \frac{2000}{0.02} \times 0.1 = 100000\ \text{Pa}$$

41. Describe an experiment to measure the surface tension of a liquid using the capillary rise method. Provide the formula used in this method.

Answer: In the capillary rise method, a clean glass tube with a very fine bore, called a capillary tube, is taken. The tube is dipped vertically into the liquid whose surface tension is to be measured. The liquid rises in the tube due to capillary action. The height (h) to which the liquid rises in the capillary tube is measured. The radius (r) of the capillary tube is also measured.

The formula used to calculate the surface tension (T) of the liquid using the capillary rise method is:

$$T = \frac{2.h.r.g}{\cos\ \theta}$$

42. Explain the factors affecting capillary action.

Answer: Capillary action is influenced by the radius of the tube, surface tension, and the contact angle between the liquid and the tube's surface. Smaller radii and greater surface tension result in higher capillary rise, while larger contact angles decrease it.

43. **A capillary tube of inner radius 0.5 mm is dipped vertically in liquid of specific gravity 8.0, surface tension 545 dyne cm^{-1} and angle of contact is 120°. Find the elevation or depression of liquid in the tube.**

[PYQ NIOS Oct 2022]

Answer:

Given: radius = 0.5 mm, Specific gravity = 8.0,
Surface tension = 545 dyne/cm, Angle = 120°

We need to calculate the depression of a liquid in the tube Using formula of deviation of liquid in the tube

$$h = \frac{2.T\cos\theta}{r\,\rho\,g}$$

$$\Rightarrow \quad h = \frac{2\times 545\times\cos 120^\circ}{0.5\times 10^{-1}\times 8\times 9.8} = -139.03$$

Negative sign shows the deviation of liquid in the capillary tube**.** Hence, The depression of a liquid in the tube is 139.03.

44. **What is surface tension?**

Answer: Surface tension is the property of a liquid surface that allows it to resist an external force. It arises due to the cohesive forces between the liquid molecules at the surface. Surface tension tends to minimize the surface area, causing liquid drops to form spherical shapes and enabling objects like water striders to float on water.

45. **What is the pressure inside the drop of mercury of radius 3.00 mm at room temperature? The surface tension of mercury at that temperature (20 °C) is 4.65 × 10^{-1} N m^{-1}. The atmospheric pressure is 1.01 × 10^{5} Pa. Also, give the excess pressure inside the drop.**

Answer: Given: Surface tension of mercury, S = 4.65 × 10^{-1} N m^{-1} Radius of the mercury drop, r = 3.00 mm = 3 × 10^{-3} m Atmospheric pressure, P_0 = 1.01 × 10^{5} Pa.

We know that total pressure inside the mercury drop = excess pressure inside mercury + atmospheric pressure = 2 S / r + P_0 = $\left(\frac{2 \times 4.65 \times 10^{-1}}{3 \times 10^{-3}}\right)$ + 1.01 × 10^5

= 1.0131 × 10^5 Pa = 1.01 × 10^5 Pa

Excess pressure inside mercury drop = 2 S / r = $\left(\frac{2 \times 4.65 \times 10^{-1}}{3 \times 10^{-3}}\right)$ = 310 Pa.

46. A spherical particle with a radius of 5µm is settling in water ($\eta = 0.001$ Pa) under the influence of gravity (g = 9.8 m/s^2). Calculate the terminal velocity of the particle according to Stokes' law.

Answer: Using Stokes' law, terminal velocity = V_t = $\frac{2\,r^2\,g}{9\eta}$

$$\Rightarrow \quad V_t = \frac{2\,(5 \times 10^{-6})^2 \times 9.8}{9 \times 0.001} = 5.56 \times 10^{-4} \text{ m/s.}$$

47. A water stream at ground level has a velocity of 10m/s . If the stream reaches a height of 20m above the ground, calculate the decrease in pressure using Bernoulli's principle.

Answer: Using Bernoulli's principle, the decrease in pressure (ΔP) can be calculated as –:

$$\Delta P = \rho\, g\, h \times \frac{1}{2}\rho \times v^2$$

$$\Rightarrow \quad \Delta P = 1000 \times 9.8 \times 20 \times \frac{1}{2} 1000 \times 10^2$$

$$\Rightarrow \quad \Delta P = 200000 \text{ Pa.}$$

Long Answer Questions

48. Discuss the practical applications of atmospheric pressure in everyday life. Provide examples of how atmospheric pressure is utilized in various devices and processes.

Answer: Atmospheric pressure has numerous practical applications in everyday life. It is crucial in the operation of barometers, altimeters, and weather instruments, providing valuable information about weather patterns. Atmospheric pressure is used in vacuum cleaners, where low pressure inside the cleaner creates suction, pulling in dirt and debris. It is also employed in siphoning liquids, where atmospheric pressure assists in the flow of fluids from one container to another. Additionally, atmospheric pressure is fundamental in the functioning of drinking straws, syringes, and even in the inflation of balloons. These applications demonstrate the significance of atmospheric pressure in various devices and processes that we encounter daily.

49. **Explain Pascal's law and its applications in fluid mechanics. Provide examples of practical applications where Pascal's law is utilized.**

Answer: Pascal's law states that a change in pressure applied to an enclosed fluid is transmitted undiminished in all directions. It has various applications in fluid mechanics, such as in hydraulic systems. One practical example is the hydraulic lift, where a small force applied to a small piston creates pressure in the fluid, which is transmitted equally in all directions. This principle is used in car brakes, hydraulic jacks, and heavy machinery, where a small force applied to a piston results in a larger force being exerted by a larger piston.

50. **Explain the application of Pascal’s law in hydraulic presses. Discuss how hydraulic presses work, and provide an example illustrating the advantage of using hydraulic presses in manufacturing processes.**

Answer: Hydraulic presses utilize Pascal’s law to amplify force. In a hydraulic press, a small force applied to a small piston generates pressure in the hydraulic fluid, which is then transmitted undiminished to a larger piston. This larger piston, with a greater surface area, exerts a significantly larger force. For example, in metal forming processes, hydraulic presses are used to shape metal sheets into various forms. By applying Pascal’s law, the hydraulic press allows manufacturers to achieve precise and powerful shaping operations, ensuring high-quality and uniform products in industries such as automotive manufacturing and metal fabrication.

51. **A soap bubble has a radius of 2 cm. Calculate the excess pressure inside the soap bubble due to surface tension. Given that the surface tension of the soap solution is 0.03 N/m.**

Answer: The excess pressure inside a soap bubble can be calculated using the formula $P_{excess} = \frac{2T}{R}$,

Given → T = 0.03 N/m , R = 2 cm = 0.02 m

$$\Rightarrow P_{excess} = \frac{2\times0.03}{0.02} = 0.03 \text{ Pa} = 3 \text{ K Pa}$$

52. **(a) What is the largest average velocity of blood flow in an artery of radius 2×10^{-3}m if the flow must remain laminar?**

(b) What is the corresponding flow rate? (Take the viscosity of blood to be 2.084×10^{-3} Pa s)

Answer: Given → Radius of the vein, $r = 2 \times 10^{-3}$ m,

Diameter = $d = 4 \times 10^{-3}$ m,

Viscosity of blood , $\eta = 2.08 \times 10^{-3}$ m,

Density of blood, $\rho = 1.06 \times 10^{3}$ kg/m^3

(a) We know Reynolds' number for laminar flow, $N_R = 2000$

Therefore, the greatest average velocity of blood is $V_{AVG} = \frac{N_R \eta}{\rho\, d}$

$$\Rightarrow V_{AVG} = \frac{2000 \times 2.08 \times 10^{-3}}{1.06 \times 10^{3} \times 4 \times 10^{-3}} = 0.983 \text{m/s}$$

(b) And, flow rate $R = V_{AVG}\, \pi r^2 = 0.983 \times 3.14 \times (2 \times 10^{-3})^2 = 1.235 \times 10^{-6}$ m^3/s.

53. **Define terminal velocity. Derive an expression for it for a spherical body of radius r falling through a viscous fluid.** **[PYQ NIOS Oct. 2022]**

Answer: Terminal velocity is the constant speed that a freely falling object eventually reaches when the resistance of the medium prevents further acceleration.

To derive an expression for terminal velocity for a spherical body of radius r falling through a viscous fluid, we can use Stokes' law,

Stokes' law states that the drag force (F_d) acting on a spherical object is given by:

$$F_d = 6\pi\eta r v_t$$

The gravitational force (F_g) acting on the object is given by:

$$F_g = \frac{4}{3}\pi r^3 \rho f g$$

At terminal velocity, the drag force F_d is equal in magnitude to the gravitational force F_g .

$$F_d = F_g$$

$$\Rightarrow \; 6\pi\eta r \, v_t = \frac{4}{3}\pi r^3 \rho_f \, g$$

$$\Rightarrow \; \boxed{v_t = \frac{2}{9}\frac{r^2(\rho_p - \rho_f)g}{\eta}}$$

54. **How does the concept of velocity gradient impact the design of systems in industries like petroleum, chemical, or food processing? Provide specific examples.**

Answer: In industries like petroleum, chemical, and food processing, understanding the velocity gradient is essential for designing efficient systems. For instance, in petroleum processing, it helps optimize the flow of crude oil through pipelines, ensuring a consistent and smooth transportation process. In food processing, knowledge of velocity gradients aids in designing mixers and pumps, ensuring uniform blending and processing of ingredients. By considering velocity gradients, engineers can enhance the efficiency of these industrial systems, leading to cost-effective and reliable operations.

55. **Discuss the practical applications of the equation of continuity in fluid dynamics.**

Answer: The equation of continuity is fundamental in various applications, including fluid dynamics in pipelines, blood circulation in the human body, and aviation. In pipelines, it ensures a consistent flow rate by maintaining the balance between the cross-sectional area and fluid velocity. In the human circulatory system, it governs blood flow through arteries and veins, helping to maintain steady circulation. In aviation, the equation of continuity is applied in the design of aircraft wings and engine components, ensuring optimal airflow and performance.

56. **On the basis of Stokes' law, explain**

(a) Why a soldier opens his parachute close to the ground, when he jumps from a flying aeroplane?

(c) Why rain drops reaching the earth do not have very high kinetic energy ?

[PYQ NIOS , Oct 2021]

Answer: (a) When a soldier jumps from a flying aeroplane, he falls with acceleration due to gravity g but due to viscous drag in air, the acceleration goes on decreasing till he acquires terminal velocity. The soldier then descends with constant velocity and opens his parachute close to the ground at a pre-calculated moment, so that he may land safely near his destination.

(b) When raindrops fall under gravity, their motion is opposed by the viscous drag in air. When viscous force becomes equal to the force of gravity, the drop attains a terminal velocity. That is why rain drops reaching the earth do not have very high kinetic energy.

57. **Mercury has an angle of contact equal to 140° with soda lime glass. A narrow tube of radius 1.00 mm made of this glass is dipped in a trough containing mercury. By what amount does the mercury dip down in the tube relative to the liquid surface outside? The surface tension of mercury at the temperature of the experiment is 0.465 N m^{-1}. Density of mercury = 13.6×10^3 kg m^{-3}.**

Answer: Given→ $\rho = 13.6 \times 10^3$ kg/m^3 , $S = 0.465$ N m^{-3},
$\theta = 140°$, $r = 1$ mm $= 1 \times 10^{-3}$ m

Let the dip in the depth of mercury = h,
Acceleration due to gravity = g = 9.8 m/s^2.

We know, surface tension S = $\frac{hg\rho r}{2cos\Theta}$

$$\Rightarrow h = \frac{2Scos\Theta}{g\rho r}$$

$$\Rightarrow h = \frac{2\times0.465\times cos140^{\circ}}{13.6\times9.8}$$

= -5.34 mm

58. **An airplane is flying at a speed of 250 m/s at an altitude where the air pressure is 80 K Pa and the density of air is 1.2 kg/m^3. Calculate the**

pressure on the upper surface of the airplane's wings according to Bernoulli's principle. (Take g = 9.8 m/s^2).

Answer: According to Bernoulli's principle, the total pressure in a fluid system remains constant.

The pressure on the upper surface of the wings can be calculated using the formula $P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$

where P_1 and v_1 are the pressure and velocity at the given altitude, and P_2 and v_2 are the pressure and velocity on the upper surface of the wings.

Rearranging the formula, $P_2 = P_1 + \frac{1}{2}\rho\,(v_1^2 - v_2^2)$ and substituting the given values,

$$P_2 = 80 \times 10^3 + \frac{1}{2} \times 1.2 \times (250^2 - 0^2) = 205 \times 10^3 \text{ Pa}$$

Very long answers questions

59. State and prove Archimedes’ principle mathematically.

Answer:

∗ Archimedes’ Principle:

Archimedes' principle states that the upward buoyant force that is utilized on a body immersed in a fluid, whether fully or partially plunged, is equal to the weight of the fluid that the body displaces.

∗ Mathematical proof:

Consider an object of volume V submerged in a fluid of density ρ. The volume of the fluid displaced by the object is also V (since the object takes up that much space in the fluid).

The weight of the fluid displaced is given by $W_{fluid} = \rho \times V \times g$, where g is the acceleration due to gravity.

The weight of the object is = $W_{object} = m \times g$, where m is the mass of the object.

According to Archimedes' principle, the buoyant force $F_{buoyant}$ experienced by the object is equal to the weight of the fluid displaced:

$$F_{buoyant} = W_{fluid}$$

$$F_{buoyant} = \rho \times V \times g \qquad \text{......Eq. 1}$$

The object is in equilibrium, so the weight of the object is balanced by the buoyant force:

$$F_{buoyant} = W_{object}$$

$$\rho \times V \times g = m \times g \qquad \text{.....Eq. 2}$$

From Eq. 1 and Eq. 2, it is clear that: $\rho \times V = m$

This equation states that the mass of the fluid displaced ($\rho \times V$) is equal to the mass of the object (m). This relationship holds true for any object submerged in a fluid.

Hence proved Archimedes' principle mathematically.

60. Explain Pascal's law in detail, emphasizing its significance in understanding the behavior of fluids under pressure. Discuss how Pascal's law is applicable in various hydraulic systems, providing examples from real-life applications such as hydraulic brakes and lifts.

Answer:

* Pascal's law:

Pascal's law states that in a confined fluid at rest, any change in pressure applied at any point in the fluid is transmitted undiminished throughout the fluid in all directions. This principle is crucial in understanding the behavior of fluids under pressure.

* Pascal's law in hydraulic systems

In hydraulic systems, Pascal's law finds extensive applications. For instance, in hydraulic brakes, when the brake pedal is pressed, it exerts pressure on a small piston connected to a hydraulic fluid. According to Pascal's law, this pressure is transmitted undiminished through the fluid to a larger piston, which applies a greater force to the brake pads, allowing effective braking. Similarly, hydraulic lifts operate on the same principle, where a small force applied to a small piston results in a large force lifting a heavy load due to the incompressibility and transmission of pressure in the hydraulic fluid.

61. Two capillary tubes having diameters 3.0 mm and 6.0 mm are joined together to form a u-tube open at both ends. If water is contained in the u-tube, find the level difference in the two limbs of the tube due to capillarity.

(Given: Surface Tension of water = 7.3×10^{-2} Nm^{-1} angle of contact = 0, density of water = 10^3 Kgm^{-3} and g = $9.8ms^{-2}$) **[PYQ NIOS , Jan 2021]**

Answer: Diameter of the first bore, $d_1 = 3.0$ mm $= 3 \times 10^{-3}$m

Hence, the radius of the first bore, $r_1 = d_1 / 2 = 1.5 \times 10^{-3}$m

Diameter of the first bore, $d_2 = 6.0$ mm $= 6 \times 10^{-3}$m

Hence, the radius of the second bore, $r_2 = d_2/2 = 3 \times 10^{-3}$m

Surface tension of water, $s = 7.3 \times 10^{-2}$ Nm^{-1}

Angle of contact between the bore surface and water, $\theta = 0°$

Density of water, $\rho = 1.0 \times 10^3$ kg/m^{-3}

Acceleration due to gravity, $g = 9.8m/s^2$

Let h_1 and h_2 be the heights to which water rises in the first and second tubes respectively.

These heights are given by the relations:

$$h_1 = \frac{2s\cos\theta}{r_1 \rho g} \quad \text{..... (i)}$$

$$h_2 = \frac{2s\cos\theta}{r_2 \rho g} \quad \text{..... (ii)}$$

The difference between the levels of water in the two limbs of the tube can be calculated as:

$$h_1 - h_2 = \frac{2s\cos\theta}{r_1 \rho g} - \frac{2s\cos\theta}{r_2 \rho g}$$

$$\Rightarrow \frac{2s\cos\theta}{\rho g}\left[\frac{1}{r_1} - \frac{1}{r_2}\right]$$

$$\Rightarrow \frac{2\times 7.3\times 10^{-2}\times 1}{10^{3}\times 9.8}\left[\frac{1}{1.5\times 10^{-3}}-\frac{1}{3\times 10^{-3}}\right]$$

$$\Rightarrow 4.966\times 10^{-3}\text{m}$$

$$\Rightarrow 4.97\text{ mm}$$

Hence, the difference between levels of water in the two bores is 4.97 mm.

62. Give an explanation about the fluid flow and its types. Write the name of various type of liquid flow. Make a table to differentiate the streamline flow and turbulent flow.

Answer: Fluid flow is generally the motion of a fluid that is subjected to different unbalanced forces. It is mainly a part of fluid mechanics and fluid flow generally deals with the dynamics of the fluid. The motion of the fluid continues till different unbalanced forces are applied to the fluid.

There are five types of fluids that have been identified: Ideal fluid, Real fluid, Newtonian fluid, Non-Newtonian fluid, and Ideal plastic fluid.

* Types of fluid flow

The six different types of fluid flow are –:

- Steady and Unsteady
- Uniform and Non-Uniform
- Laminar and Turbulent
- Compressible and In-compressible
- Rotational and Irrotational
- One, Two, and Three-dimensional Fluid Flow

* Streamline flow and Turbulent flow is differentiate in table given below –:

Streamline flow	Turbulent flow
1. The smooth flow of a fluid, with velocity smaller than certain critical velocity (limiting value of	**1.** The irregular and unsteady flow of a fluid when its velocity increases beyond critical velocity are called

velocity), is called streamline flow or laminar flow of a liquid.	turbulent flow.
2. In a streamlined flow, the velocity of a fluid at a given point is always constant.	**2.** In a turbulent flow, the velocity of a fluid at any point does not remain constant.
3. Two streamlines can never intersect, i.e., they are always parallel and hence can never form eddies.	**3.** Ina turbulent flow, at some points, the fluid may have a rotational motion which gives rise to eddies.
4. Streamline flow over a plane surface can be assumed to be divided into a number of plane layers. In a flow of liquid through a pipe of uniform cross – sectional area, all the streamlines will be parallel to the axis of the tube.	**4.** A flow tube loses its order and particles move in a random direction.
5. Examples –: (i) Flow in rivers and canals, (ii) Blood flow in veins (iii) Water coming out from a tap	**5.** Examples –: (i) flow over the golf ball. (ii) clean air turbulence is usually experience during flight take – offs. (iii) flow of blood through arteries during heart conditions.

63. How do the properties of fluids, such as viscosity and surface tension, affect the behavior of substances in various natural phenomena and industrial processes?

Answer: The properties of fluids, including viscosity and surface tension, play crucial roles in various natural phenomena and industrial processes. Let's explore how these properties affect the behavior of substances:

- **Viscosity:**

Natural Phenomena:

- Lava Flow: Viscosity determines the speed at which lava flows during volcanic eruptions. More viscous lava flows slower and solidifies faster.
- Glacial Movement: Glaciers flow due to their viscosity. Higher viscosity leads to slower movement, shaping landscapes over centuries.
- Blood Circulation: Blood viscosity affects its flow in arteries and veins. Abnormal viscosity can impact cardiovascular health.

Industrial Processes:

- Oil Refining: Viscosity affects the flow of crude oil through pipelines. Refineries adjust viscosity for efficient processing.
- Paint Production: Viscosity influences paint consistency. Paints with varied viscosity are used for different applications, like brushes or spray guns.
- Food Industry: Viscosity determines the texture of products like sauces and creams. Manufacturers control viscosity for desired mouthfeel.

∗ Surface Tension:

Natural Phenomena:

- Raindrop Formation: Surface tension shapes raindrops. Water droplets form spheres due to surface tension, affecting rainfall patterns.
- Capillary Action: Surface tension allows water to rise in narrow tubes against gravity, vital for plant roots' water uptake.
- Insect Walking on Water: Surface tension enables small insects like water striders to walk on water without sinking.

Industrial Processes:

- Detergent Action: Detergents reduce surface tension, helping water spread and penetrate fabrics. This aids in effective cleaning.

- Printing: In offset printing, ink adheres to the printing plate due to surface tension, ensuring precise image transfer.
- Chemical Mixing: Surface tension affects the mixing of liquids. Controlling surface tension is vital in chemical processes and drug formulations.

In summary, viscosity and surface tension are fundamental fluid properties that impact diverse natural phenomena and industrial processes.

64. Explore the concept of Bernoulli's principle and its applications in aviation, sports, and weather phenomena like wind patterns and ocean currents.

Answer:

∗ Bernoulli's Principle:

Bernoulli's principle states that in a fluid flow, an increase in the speed of the fluid occurs simultaneously with a decrease in its pressure. This principle is based on the conservation of energy in a fluid flow system. As the speed of a fluid increases, its internal pressure decreases, and vice versa.

∗ Applications:

1. Aviation:

- Airfoil Design: Bernoulli's principle explains lift generation in aircraft wings. The shape of an airplane wing is designed such that the airfoil's upper surface is curved, causing the air to move faster over it. This reduces pressure on the upper surface, creating lift and enabling flight.
- Lift in Flight: During flight, the faster airflow over the wing's curved upper surface results in lower pressure compared to the slower airflow beneath the wing, generating lift that keeps the aircraft aloft.

2. Sports:

- Ball Games: In sports like soccer, tennis, and golf, players exploit Bernoulli's principle to control the ball's trajectory. Spin applied to a ball causes differences in air pressure on its surfaces, altering its path through the air. For instance, a spinning soccer ball curves due to uneven air pressure, a phenomenon known as the Magnus effect.

- Aerodynamics in Racing: Racing car designers utilize Bernoulli's principle to enhance aerodynamics, ensuring the vehicles generate downforce to increase traction and stability during high-speed turns.

3. Weather Phenomena:

- Wind Patterns: Bernoulli's principle contributes to the formation of wind patterns. Differential heating of the Earth's surface causes air to move from high to low-pressure areas. As air moves, it follows the principle, affecting wind speeds and directions globally, influencing weather patterns and climate.

- Ocean Currents: Ocean currents, driven by variations in temperature and salinity, operate similarly to wind patterns. The principles of fluid dynamics, including Bernoulli's, help scientists understand the movement and behavior of ocean currents, which impact climate and marine ecosystems.

In essence, Bernoulli's principle finds applications in various fields, from aviation and sports to understanding complex weather phenomena.

Its principles are fundamental in designing aircraft, sports equipment, and predicting natural phenomena, contributing significantly to scientific and technological advancements.

65. Based on Bernoulli’s theorem, describe the working of a ‘Flow meter’ to measure rate of flow of liquids through pipes. Draw its diagram.

[PYQ NIOS , Oct 2021]

Answer: Bernoulli's theorem states that within a flowing fluid, an increase in the speed of the fluid occurs simultaneously with a decrease in its pressure or potential energy. This principle is fundamental to the operation of various flow meters, including differential pressure flow meters, which are commonly used to measure the flow rate of liquids in pipes.

A common type of flow meter based on Bernoulli's theorem is the Venturi meter. Here's a description of how it works and a simplified diagram:

∗ Working Principle:

Construction: The Venturi meter consists of a pipe with a gradually narrowing section in the middle called the throat.

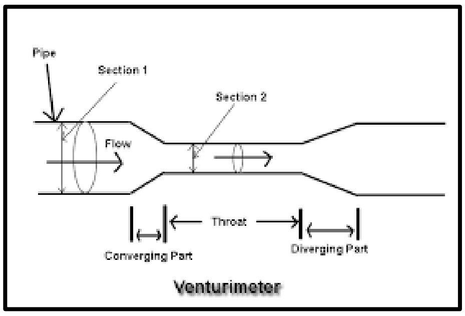
Flow Measurement: When a fluid flows through the wider portion of the pipe before the throat, its speed is relatively low, and the pressure is relatively high according to Bernoulli's theorem.

Throat: As the fluid enters the throat, the cross-sectional area decreases, causing the fluid to accelerate. According to Bernoulli's theorem, the increase in fluid speed is accompanied by a decrease in pressure.

Pressure Difference: The pressure difference between the wider section of the pipe and the throat is measured using pressure taps placed at these points.

Flow Calculation: By measuring this pressure difference, the flow rate of the fluid can be calculated using specific equations that relate the pressure drop to the flow rate.

* Diagram:



In this diagram, the fluid enters from the left side of the wider section, accelerates as it passes through the throat, and then continues into the wider section on the right.

The pressure taps are typically located before and after the throat to measure the pressure difference, allowing for the calculation of the flow rate.

11

Thermodynamics

Short summary

What do we learn

Quick Revision

➢ *What is thermodynamics?*

Thermodynamics is the branch of physics that deals with the concepts of heat and temperature.

It also deals with the transformation of heat energy into other and vice – versa.

➢ *Heat*

Heat is the form of energy transferred between two (or more) systems or a system and its surroundings because of temperature difference.

- It is denoted by ‘Q’.
- S.I. unit is of heat is joule.
- Practical unit is calorie.

1 Kcal = 1000 cal
1 cal = 4.18 J

- The ratio of work done (W) to heat produced (Q) is constant.

➢ *Temperature*

Temperature is defined as the degree of hotness or coldness of a body.

Heat flows from higher temperature to lower temperature.

➢ *Thermal equilibrium*

Two bodies are said to be in thermal equilibrium when both the bodies are at the same temperature.

- Temperature of a body is the property which determines whether or not it is in thermal equilibrium with other bodies.

➢ *Thermodynamic system*

An assembly or combination of atom having a certain value of pressure, volume and temperature is called “Thermodynamics system”.

- Every system is enclosed by a arbitrary surface called boundary.

- Everything which is outside the system and affect it, called surroundings.

There are three types of systems –:

1. Open system
2. Closed system
3. Isolated system

(i) Open system: It exchange both energy and matter with the surrounding.

(ii) Closed system: It exchange only energy (not matter) with the surroundings.

(iii) Isolated system: It exchange neither energy nor matter with the surrounding.

➢ *Thermodynamic variable*

Physical quantities such as pressure, volume and temperature are termed as thermodynamic variable.

➢ *Indicator diagram*

Pressure – volume graph which indicates the variation of pressure with respect to volume during a thermodynamic process of a system and is known as indicator diagram.

➢ *Thermodynamic process*

If any thermodynamic variable change while going from one equilibrium state to another, the system is said to execute a thermodynamic process.

➢ *Types of thermodynamic process*

1. Reversible process
2. Irreversible process
3. Isothermal process
4. Isobaric process
5. Isochoric process
6. Adiabatic process

❶ *Reversible process:* A process in which the system and surroundings can be returned to the original conditions from the final state without producing any changes in the thermodynamics properties of the universe, if process is reversed.
Example –: Very slow evaporation or condensation.

❷ *Irreversible process:* Any process which is not reversible exactly is an irreversible process.
Example –: Sudden expansion or contraction.

➢ *Isothermal process*

A thermodynamic process that occurs at constant temperature is called isothermal process.

In this process, P and V change but T = constant *i.e.*, change in temperature $\Delta T = 0$.

(1) Condition for isothermal process:

(i) The walls of the container must be perfectly conducting.

(ii) The speed of process should be very slow.

(2) Equation of state:

$$\boxed{PV = \text{constant}}$$

(3) Examples:

(i) Melting process

(ii) Boiling process.

(4) work done

$$W = \mu RT \log_e\left(\frac{P_i}{P_f}\right) = 2.303\ \mu RT \log_{10}\left(\frac{P_i}{P_f}\right)$$

(5) Heat supplied in isothermal process:

$$\Delta Q = \Delta W$$

i.e., heat supplied is used to do work against external surrounding.

- The thermal equilibrium is always maintained.
- In such a process, ΔQ, ΔU and ΔW are finite.

➢ *Isobaric process*

It is a thermodynamic process which occurs at constant pressure.

(1) Condition for isothermal process:

(i) The pressure of the system remains constant throughout the process.

(ii) Process should occur in open container.

(2)Equation of state: $PV = nRT$

(3) Examples:

(i) Heating of water (ii) Air compressor

(4) work done: $w = P \times \Delta V$

Where, ΔV is the change in volume ($V_f - V_i$).

➢ *Isochoric process*

A thermodynamic process that occurs at constant volume.

(1) Condition for isochoric process:

Isochoric processes can occur in closed containers or rigid vessels where the volume cannot change.

(2) Equation of state:

$$PV = nRT$$

(3) Examples:

(i) Pressure cooker

(ii) Air conditioner

(4) work done: $W = 0$

In this process, volume of the gas remains constant so that no work is done.

➢ *Adiabatic process*

A thermodynamic process in which no exchange of thermal energy occurs.

(1) Condition for adiabatic process:

The system is thermally isolated from its surroundings.

(2) Examples: Expansion or compression of gas in a cylinder.

(3) work done: $w = \Delta U$

(4) Change in internal energy:

$$\Delta Q = 0$$

➢ Zeroth law of thermodyamics

It states that ***"If two bodies or systems A and B are separately in thermal equilibrium with a third system C, then A and B are in thermal equilibrium with each other."***

➢ Internal energy of a system

(a) Internal kinetic energy: The total kinetic energy of the molecules due to their motion.

(b) Internal potential energy: The energy arising due to the inter-molecular forces.

The total internal energy of a system is the sum of kinetic energy due to random motion of molecules and potential energy due to interactions among the molecules.

Internal energy of a system = Kinetic energy of molecules + Potential energy of molecules

➢ first law of thermodynamics

It states that ***"change in internal energy of a system during a thermodynamic process is equal to the sum of the heat given to it and the work done on it".***

$$\Delta Q = \Delta U + \Delta W$$

➢ first law of thermodynamics

$$\Delta Q = \Delta U + \Delta W$$

Where,
ΔQ = Heat supplied to the system by surroundings
ΔW = Work done by the system of the surroundings
ΔU = Change in internal energy of system

➢ Sign convention

ΔQ	
+Ve	When heat is supplied to the system
–Ve	When heat is drawn from the system
ΔW	
+Ve	When work done by gas (expansion)
–Ve	When work done on gas (compression)
ΔU	
+Ve	When temp. increases U decreases
–Ve	When temp. decreases U increases

➢ Limitations of first law

It doesn't indicate –:
1. direction of flow of heat
2. conditions under which heat can converted into mechanical work
3. extent to which heat energy can be converted into mechanical work.

➢ *Second law of thermodynamics*

Second law of thermodynamics can be state in two different ways –:

❶ *Kelvin Planck's statement*

It is based on the performance of heat engine.

"It is impossible for any system to absorb heat from a reservoir at a fixed temperature and convert whole of it into work."

❷ *Clausius statement*

It is based on the performance of refrigerator.

"It is impossible for any process to have as its sole result to transfer heat from a colder body to a hotter body without any external work."

➢ *Carnot engine*

Carnot designed a theoretical engine. This engine cannot be realized in actual practice.

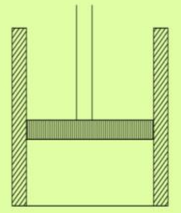


Fig. 11.5 : The cylinder with working substance

A Carnot Engine has following main parts:

① cylinder ②source

③sink

④working substances

⑤insulating substances

➢ *Carnot cycle*

The working substance of the engine undergoes a cycle known as Carnot cycle.

It consists of the following four strokes:

(i) Isothermal expansion

(ii) Adiabatic expansion

(iii) Isothermal compression

(iv) Adiabatic compression

➢ *Efficiency of Carnot cycle* (η)

$$\eta = \frac{\text{work done}}{\text{heat input}} = \frac{W}{Q_1}\ ;\ \eta = 1 - \frac{T_2}{T_1}$$

T_1 and T_2 are in Kelvin.

(i) Efficiency of a heat engine depends only on temperatures.

(ii) Efficiency of a heat engine is always lesser than unity, *i.e.*, whole of heat can never be converted into work which is in accordance with second law.

➢ *Carnot theoram*

Carnot's reversible engine working between two given temperature is considered to be the most efficient engine.

Question – Answer

① MCQs

1. Thermodynamics means:

(A) study of the relationship between heat and other forms of energy
(B) study of the conversion of chemical energy to other forms of energy
(C) study of the relationship between mechanical energy to other forms of energy
(D) study of the conversion of mechanical energy to other forms of energy

Answer: **(A)** study of the relationship between heat and other forms of energy.

2. What is the primary difference between heat and temperature?

(A) Heat is a measure of thermal energy, while temperature is the transfer of energy.
(B) Heat is the transfer of energy, while temperature is a measure of thermal energy.
(C) Heat and temperature are synonymous terms.
(D) Temperature is the measure of energy, while heat is the transfer of thermal energy.

Answer: **(B)** Heat is the transfer of energy, while temperature is a measure of thermal energy.

3. If no energy or matter is exchanged between a system and its surroundings, the system is classified as:

(A) Closed system
(B) Open system
(C) Isolated system
(D) Adiabatic system

Answer: **(C)** Isolated system

4. Which of the process described below are irreversible?

(A) The increase in temperature of an iron rod by hammering it
(B) A gas in a small container at a temperature T_1 is brought in contact with a

big reservoir at a higher Temperature. T_2 which inverses the temperature of the gas

(C) A quasi - state isothermal expansion of an ideal gas in cylinder fitted with a frictionless piston

(D) An ideal gas is enclosed in a piston cylinder arrangement with adiabatic Walls. A weight W is added to the piston, resulting in compression of a gas

Answer: **(A)** The increase in temperature of an iron rod by hammering it.

5. **Which of the following parameters does not characterize the thermodynamic state of matter?**

(A) Work (B) Volume
(C) Pressure (D) Temperature

Answer: **(A)** Work

6. **Which of the following statement is correct for any thermodynamic system?**

(A) The internal energy changes in all processes.
(B) Internal energy and entropy are state function.
(C) The change in entropy can never be zero.
(D) The work done in an adiabatic process is always zero.

Answer: **(B)** Internal energy and entropy are state function.

7. **An ideal gas undergoes four different process from the same initial state. (Fig.). Four processes are adiabatic, isothermal, isobaric & isochoric. Out of 1, 2, 3 & 4 which one is adiabatic?**

(A) 4 (B) 3 (C) 2 (D) 1

Answer: **(C)** 2

8. **An ideal gas undergoes isothermal process from some initial state i to final state f. Choose the correct alternative**

(A) $dU = 0$ (B) $d\theta = 0$ (C) $d\theta = dU$ (D) $dQ = dw$

Answer: **(A)** $dU = 0$

9. During an adiabatic process, the increase of a gas is found to be proportional to the cube of its temperature. The ratio of Cp/Cv for the gas is:

(A) $\frac{3}{2}$ (B) $\frac{4}{3}$ (C) 2 (D) $\frac{5}{3}$

Answer: (A) $\frac{3}{2}$

10. Which of the following process is used to do maximum work done on the ideal gas if the gas is compressed to half of its initial volume?

(A) Isothermal (B) Isochoric

(C) Isobaric (D) Adiabatic

Answer: (D) Adiabatic

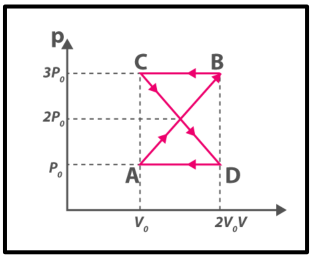
11. For all the reactions what is the nature of the chemical dissociation?

(A) Exothermic (B) Reversible

(C) Endothermic (D) Reversible and endothermic

Answer: (D) Reversible and endothermic

12. ABCDA is a cyclic process explaining the thermodynamic process. What is the work done by the system in the cycle.

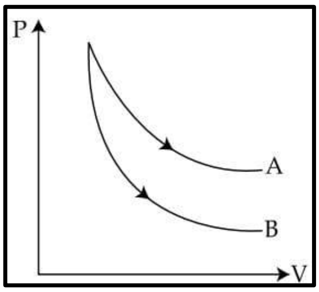


(A) Zero (B) $\frac{\rho_0 V_0}{2}$

(C) $\rho_0 V_0$ (D) $2\rho_0 V_0$

Answer: (A) Zero

13. The given P-V diagram show for the expansion of a gas. Which one of the following statements is true ? [PYQ NIOS Oct 2021]



(A) A is isothermal process, while B is adiabatic process

(B) A is adiabatic process, while B is isothermal process

(C) Both are isothermal processes

(D) Both are adiabatic processes

Answer: (A) A is isothermal process, while B is adiabatic process

14. Does the internal energy change when work is done on a system adiabatically?

(A) Internal energy increases

(B) Internal energy decreases

(C) Internal energy remains constant

(D) Internal energy is unrelated to work

Answer: (A) Internal energy increases

15. What is a limitation of the first law of thermodynamics?

(A) It fails to indicate the direction of heat flow

(B) It does not conserve mass during processes

(C) It is not applicable to chemical reactions

(D) It cannot explain changes in temperature with height

Answer: (A) It fails to indicate the direction of heat flow

16. How does a refrigerator differ from a heat engine in the context of the Second Law of Thermodynamics?

(A) A refrigerator converts heat into work, while a heat engine transfers heat from a colder to a hotter body

(B) A refrigerator transfers heat from a hotter to a colder body, while a heat engine converts heat into work

(C) Both refrigerator and heat engine operate under the same principles

(D) Refrigerators and heat engines are synonymous terms

Answer: (B) A refrigerator transfers heat from a hotter to a colder body, while a heat

17. A Carnot engine, having an efficiency of $\eta = \frac{1}{10}$ as heat engine is used as a refrigerator. If the work done on the system is 10J the amount of energy absorbed from the reservoir at lower temperature is:

(A) 99 J (B) 90 J (C) 1 J (D) 100 J

Answer: (B) 90 J

18. **A Carnot engine is working between steam point and ice point. Its efficiency will be :** **[PYQ NIOS Jan 2021]**

(A) 24.9% (B) 25.7% (C) 26.8% (D) 28.8%

Answer: **(C)** 26.8%

19. **Out of the following the law of a thermodynamics law actually is:**

(A) Zeroth law of thermodynamics
(B) Faraday's Law of thermodynamics
(C) Ideal Gas Law of thermodynamics
(D) Boyle's Law of thermodynamics

Answer: **(A)** Zeroth law of thermodynamics

20. **Out of the following a type of thermodynamic system is：**

(A) Open system (B) Closed system
(C) Thermally isolated system (D) All of the mentioned

Answer: **(D)** All of the mentioned

② Complete the sentence using an appropriate words

21. Isothermal, Energy, decreases, Heat engine, Indicator diagram

(1) Heat is a form of ………………..
(2) ……………. is a pressure – volume graph that indicates the variation of pressure with respect to time.
(3) If some work done by the system, its internal energy will …………….
(4) A thermodynamic process that occurs at the constant temperature is called …………….
(5) Kelvin – planck's statement is based on the performance of ……………

Answer: (1) energy, (2) indicator diagram (3) decreases, (4) isothermal process, (5) heat engine.

③ Fill in the blanks

22.

(1) ………… is the S.I. unit of heat.
(2) ………… is an example of isobaric process.

(3) Device which converts heat into work is called ....

(4) A thermodynamic process that occurs at a constant volume is called ....

Answer: (A) calorie, (B) boiling of water, (c) heat engine, (d) isochoric process.

⑤ match the following

23. **Match column – I statement with the right option of column – II**

COLUMN I	COLUMN II
A. First law of thermodynamics	(i) heat engine principle
B. Second law of thermodynamics	(ii) Conservation of energy
C. Carnot cycle	(iii) Entropy concept
D. Internal energy	(iv) Reversible process
E. Adiabatic process	(v) State function

Answer: A – ii, B – iii, C – i, D – v, E - iv

24. **Match the following:**

COLUMN I	COLUMN II
A. Isothermal expansion	(i) Heat rejection at constant temperature
B. Adiabatic expansion	(ii) Maximum efficiency cycle
C. Isothermal compression	(iii) Heat absorption at constant temperatur
D. Adiabatic compression	(iv) Reversible process
E. Efficiency of carnot cycle	(v) Work done during expansion

Answer: A – iii, B – v, C – i, D – iv, E – ii

⑥True or false

25. Internal energy of a gaseous system depends upon thermodynamics process.

⇒ False.

26. In an isothermal process, the internal energy of the system does not change.

⇒ True.

27. For an adiabatic process, process should be slow.

⇒ False.

28. For an isothermal expansion process, process should be slow.

⇒ True.

29. First law of thermodynamics is represented as ‘dQ = dU + Dw’

⇒ True.

30. The equation for adiabatic process if PV^{γ} = constant.

⇒ True.

31. The efficiency of a carnot engine working between 227°C and 27°C is 20%.

⇒ False.

32. $\Delta U = 0$ for a cyclic process.

⇒ True.

33. The system does not return to its initial state in a cyclic process.

⇒ False.

34. The total heat absorbed equals the work done by the system.

⇒ True.

35. In refrigerator the source of heat is the environment and sink of heat is the inner chamber of heat.

⇒ False.

36. If door of a working refrigerator is kept open for a long time in a closed room, the room will become cool.

⇒ False.

⑦ Very short question [2 marks of each]

37. What is the foundation of thermodynamics?

Answer: The law of conservation of energy and the observation that heat travels from a hot body to a cool body are the foundation of thermodynamics.

38. Explain how heat can be added to a system without changing its temperature?

Answer: If heat is added to a system to do only the external work then there will be no rise in temperature.

39. Draw an indicator diagram for a thermodynamic system, when it expands isothermally from volume V_1 to V_2 at pressures P_1 and P_2 respectively. [PYQ NIOS Oct 2021]

Answer:

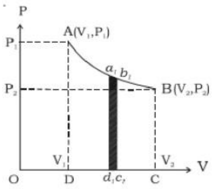


Fig. Indicator diagram

40. With the help of example, explain the meaning of thermodynamical equilibrium of a system. [PYQ NIOS Jan 2021]

Answer: Thermodynamic equilibrium, condition or state of a thermodynamic system, the properties of which do not change with time and that can be changed to another condition only at the expense of effects on other systems.

For example, the gas in a cylinder with a movable piston will be at equilibrium if the temperature and pressure inside are uniform and if the restraining force on the piston is just sufficient to keep it from moving.

41. Define the isochoric process? What kind of work will be done throughout the procedure?

Answer: The isochoric process refers to a thermodynamical process in which the volume of the system remains constant. Because the volume of the gaseous system does not change, the work done in this operation will be 0.

42. When constructing thermometers, why is mercury used?

Answer: Mercury is used to make thermometers because it has a large and useful temperature range as well as a consistent rate of expansion.

43. Distinguish between internal energy and heat energy of a body.

[PYQ NIOS April 2022]

Answer: Internal energy refers to the energy stored within a person's body. It rises when the body's temperature rises or transitions from solid to liquid or from liquid to gas. Heat is the energy transferred from one body to another due to a temperature differential.

44. Define triple point of water.

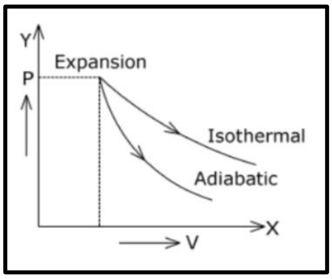
Answer: Triple point of water represents the values of pressure and temperature at which water co-exists in equilibrium in all the three states of matter.

45. Can an adiabatic process ever be isochoric? Provide reason.

Answer: No, adiabatic implies a process with no heat exchange, while isochoric means constant volume and no work is done.

46. Draw a p – v diagram for isothermal and adiabatic expansion?

Answer: Diagram of P – V for isothermal and adiabatic expansion.



47. When ice melts, the change in internal energy is greater than the heat supplied. Why?

Answer: When ice melts the increase in internal energy is greater than the heat supplied because when ice melts there is a decrease in the volume and so work is done on the system by the surroundings.

48. State the Zeroth law of thermodynamics. How many joules of work is equivalent to one calorie of heat? **[PYQ NIOS Oct 2021]**

Answer: When a body, ‘A’, is in thermal equilibrium with another body, ‘b’, and also separately in thermal equilibrium with a body ‘, C’, then body, ‘B’ and ‘C’, will also be in thermal equilibrium with each other. This statement defines the zeroth law of thermodynamics. The law is based on temperature measurement.

1 calorie = 4.186 joules

49. State first law of thermodynamics. Write its mathematical form? **[PYQ NIOS Oct 2021]**

Answer: First law of thermodynamics states that “change in internal energy of a system during a thermodynamic process is equal to the sum of the heat given to it and the work done on it”.

Mathematical form: $\boxed{\Delta U = \Delta W + \Delta Q}$

50. Write two limitation of the first law of thermodynamics.

Answer: (i) It does not give the direction of flow of heat.

(ii) It does not explain why heat cannot be spontaneously converted into work.

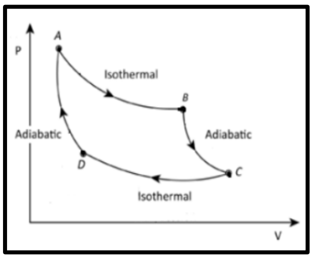
51. State the Second law of thermodynamics and write two applications of it?

Answer: According to second law of thermodynamics, when a cold body and a hot body are brought into contact with each other, heat always from hot Body to the cold body. Also, that no heat engine that works in cycle completely converts heat into work. Second law of thermodynamics is used in working of heat engine and of refrigerator.

52. How does Carnot cycle operates?

Answer: A Carnot cycle operates a follow: -

1) It receives thermal energy isothermally from some hot reservoir maintained at a constant high temperature T_H.



2) It rejects thermal energy isothermally to a constant low-temperature reservoir T_2.

3) The change in temperature is reversible adiabatic process.

Such a cycle, which consist of two isothermal processes bounded by two adiabatic processes, is called Carnot cycle.

53. Write the sign conventions for the heat and work done during a thermodynamic process?

Answer: 1) When heat is given to a system, the value of d is positive; however, when heat is supplied by a system, the value of d is negative.

2) When a gas expands, the work done is positive; however, when a gas compresses, the work done is negative.

54. Write the expressions for C_v and C_p of a gas in terms of gas constant R and γ where $\gamma = C_p/C_v$

Answer: $\gamma = C_p/C_v$

$C_p - C_v = R$

$\Rightarrow \quad C_p = \gamma C_v$

$\Rightarrow \quad (\gamma - 1) C_v = R \Rightarrow C_v = \frac{R}{\gamma - 1}$

$= \quad C_P = \frac{\gamma R}{\gamma - 1}$

55. By what methods can the internal energy of an ideal gas be changed? Give examples.

Answer: The internal energy of an ideal gas can be changed by heating or cooling the gas in a closed vessel by adiabatic compression or expansion of the gas.

56. Heat equivalent to 50 J is supplied to a thermodynamic system and 10 J work is done on the system. What is change in internal energy of the system in the process.

Answer: Here, $\Delta Q = +50$ J, $\Delta W = -10$ J

$$\Delta U = \Delta Q - \Delta W = +50 - (-10) = +60 \text{ J.}$$

57. Calculate the fall in temperature when a gas initially at 72 °C is expanded suddenly to eight times its original volume. (γ = 5/3)

Answer: $T_1 = 72° = 72 + 273 = 345$ K, $\gamma = 5/3$, initial volume = V, final volume = 8V, T_2 = ?

$$T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$$

$$\Rightarrow 345\ V = T_2\ (8V)^{\frac{5}{3}-1}$$

$$\Rightarrow T_2 = 345 \times \left(\frac{1}{8}\right)^{2/3}$$

$$\Rightarrow T_2 = 86.26 \text{ K}$$

58. Calculate the efficiency of a carnot engine working between ice point and steam point.

Answer: Temperature of source = T_1 = steam point = 373 K

Temperature of sink = T_2 = Ice point = 273 K

Efficiency , $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{273}{373} = 0.268 = 26.8\ \%$

59. One of the most efficient engine operates between 2100 K and 700K. Its actual efficiency is 40%. What percentage of its maximum possible efficiency is this? [PYQ NIOS Oct 2022]

Answer: Maximum efficiency depends only on Cold and Hot region temperatures.

$\therefore \eta = 1 - \frac{T_C}{T_H} = 1 - \frac{700}{2100} = 66.67\%$

Percentage of actual efficiency = $\frac{40}{100}$ × 100 = 60%

60. The temperatures T_1 and T_2 of heat reservoirs in the ideal car not engine are 155°C and 500°C respectively. If T_1 increase by 100°C, what will be the efficiency of the engine? **[PYQ NIOS Oct 2022]**

Answer: Given: t_1 is increase by 100° C

$$\eta = 1 - \frac{t_2}{t_1}$$

t_1 finally becomes 528K

t_2 = 773K

$$\eta = 1 - \frac{t_2}{t_1} = 1 - \frac{773}{578} = 0.47$$

$\Rightarrow$ $\eta = 0.47$

61. What is the significance of the isothermal processes in the Carnot cycle

Answer: In the isothermal processes of the Carnot cycle, the working substance exchanges heat with its surroundings while maintaining a constant temperature. These processes contribute to the efficiency of the cycle.

62. Why a room cannot be cooled by leaving the door of a refrigerator open.

Answer: Room cannot be cooled because the refrigerator takes out from stuff kept inside the refrigerator and rejects it the surroundings i.e. room.

⑤ short type question answer [3 marks of each]

63. State three conditions for reversible process.

Answer: conditions for reversible process are as follows–:

(i) The process should proceed at an extremely slow rate.

(ii) The system should remain in mechanical thermal and chemical equilibrium state at all the times with the surrounding during the process .

(iii) No dissipative forcess such as friction viscosity electrical resistance should be present.

64. Differentiate between isothermal and adiabatic process?

Answer:

	Isothermal process		Adiabatic process
1)	In this, temperature remains constant	1)	In this, no heat is added or removed.
2)	It occurs slowly	2)	It occurs suddenly.
3)	Here, system is thermally conducting to surroundings	3)	Here, system is thermally insulated from surroundings.
4)	State equation: PV = constant	4)	State equation: PV^{γ} = constant.

65. 1g of water at atmospheric pressure has volume of 1 cm^3 and when bolied it becomes 1681 cm^3 of steam. The heat of vapourisation of water is 540 cal/g. using first law of thermodynamics find the change in its internal energy in this process.

Answer: Q = mL = 1 × 540 = 540 cal

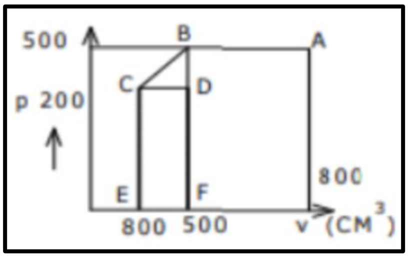
$P = 1\text{ atm} = 10^5$

$\Delta V = 1681 - 1 = 1680\text{ cm}^3 = 1680 \times 10^{-6}\text{ m}^3$

$W = P\,\Delta V = 10^5 \times 1680 \times 10^{-6} = 168\text{ J} = 168/4.2\text{ cal} = 40\text{ cal}$

$\Delta U = Q - W = 540 - 40 = 500\text{ J}$

66. Calculate the work done by the gas in going from the P–V graph of the thermodynamic behavior of a gas from point A to point B?



Answer: Work done by the gas in the process A→B is

$$W = -W_1 = -\text{ (Area under curve A B)}$$
$$W = -[(P_{AB}) \times (V_2 - V_1)]$$
$$W = -[5 \times 10^5 \times (800 - 500) \times 10^{-5}]$$

$$W = 300 \times 10^{-6}\ m^3$$

67. One kilogram molecule of a gas at 400k expands isothermally until its volume is doubled. Find the amount of work done and heat produced?

Answer: Let us consider, Initial volume, $V_1 = V$

Final volume, $V_2 = 2V$

Temperature, T = 400K (∴ process is isothermal)

$$\Rightarrow \quad W = 2.3026\ RT \log_{10}\left(\frac{V_2}{V_1}\right)$$

$$\Rightarrow \quad W = 2.3026 \times 8.3 \times 10^{-3} \times 400 \times \log_{10}\left(\frac{2V}{V}\right)$$

$$\Rightarrow \quad W = 2.3026 \times 8.3 \times 10^{-3} \times 400 \times \log_{10}(2)$$

$$\Rightarrow \quad W = 2.3026\ J$$

68. State the principle of refrigerator.

Answer: A refrigerator may be regarded as carnot's ideal heat engine working in the reverse direction. Thus when carnot engine works in opposite direction as a refrigerator, it will absorb ana mount of heat Q_2 from the sink at lower temperature T_2.

As heat is to be removed from the sink at the lower temperature, an amount of work equal to $Q_1 - Q_2$ is performed by the compressor of the refrigerator to remove heat from the sink and then to reject the total heat $Q_1 = (Q_2 + Q_1 - Q_2)$to the source through the radiator fixed at its back. It is also called a heat pump.

69. What is the ratio of slopes of P-V graphs of adiabatic and isothermal process?

Answer: The slope of P-V graph is $\frac{dP}{dV}$

For an isothermal process, (PV = constant)

So, $\frac{dP}{dV} = \frac{P}{V} \rightarrow (1)$

For an adiabatic process (PV^Y = constant)

$$\frac{dP}{dV} = \frac{YP}{V} \rightarrow (2)$$

Divide (2) by (1)

So, the ratio of adiabatic slope to isothermal slope is Y.

70. A steam engine delivers 5.4 × 10^8 J of work per minute and services 3.6 × 10^9 J of heat per minute from its boiler. What is the efficiency of the engine? How much heat is wasted per minute?

Answer: Given –: Work done by the steam engine per minute, W = 5.4 × 10^8 J

Heat supplier from the boiler, H = 3.6 × 10^9 J

Efficiency of the engine = $\eta = \frac{\text{Output energy}}{\text{input energy}} = \frac{W}{H} = \frac{5.4 \times 10^8}{3.6 \times 10^9}$ = 0.15 or 15%

Amount of heat wasted = 3.6 × 10^9 – 5.4 × 10^8 = 30.6 × 10^8 = 3.6 × 10^9 J

⑤ Long type question answer [5 marks of each]

71. Obtain an expression for work done in an isothermal process.

Answer: Let P_1, V_1 and T be the initial pressure, initial volume, and temperature. As work is done, let the gas expand to P_2, V_2 where P_2 is the reduced pressure and V_2 is the expanded volume.

Since the process is an Isothermal Process, the temperature remains constant.

We know that , W = ∫ d W

$$\Rightarrow W = \int_{V_1}^{V_2} PdV \text{ .... } (1)$$

We have the relation PV = nRT

$\Rightarrow PV = RT\ (\because n = 1 \text{ mole})$

$\Rightarrow P = \frac{RT}{V}$

Substituting the value of P in equation 1,

$$\Rightarrow W = RT\int_{V_1}^{V_2} \frac{dV}{V}$$

$$\Rightarrow W = RT[\ln V]_{V_1}^{V_2}$$

$$\Rightarrow W = RT\,[\ln V_2 - \ln V_1]$$

$$\Rightarrow W = RT\ln\frac{V_2}{V_1}$$

$$\therefore W = 2.303RT\log_{10}\frac{V_2}{V_1}$$

72. Explain the meaning of isothermal and adiabatic processes. Write the essential conditions for these processes to take place. Draw the indicator diagram of each and give one example of each. **[PYQ NIOS Oct. 2022]**

Answer:

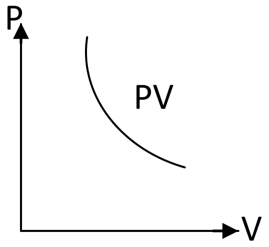
Isothermal process: A thermodynamic process that occurs at constant temperature is called isothermal process.

Essential condition for isothermal process:

(i) The walls of the container must be perfectly conducting.

(ii) The speed of process should be very slow.

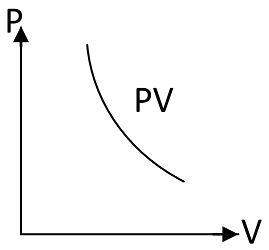
Indicator diagram:



Adiabatic process: A thermodynamic process in which no exchange of thermal energy occurs.

Essential condition for adiabatic process: The system is thermally isolated from its surroundings.

Indicator diagram:



73. Briefly describe a Carnot cycle and derive an expression for the efficiency of Carnot cycle?

Answer: The working substance of the engine undergoes a cycle known as Carnot cycle.

The following are the components of a Carnot cycle heat engine:

1) Source of heat: It is kept at a higher temperature

2) Heat sink - It is kept at a lower temperature.

3) Working material: The working substance is a perfect ideal gas.

Carnot Theorem: Carnot's reversible engine working between two given temperature is considered to be the most efficient engine.

The Carnot cycle has four stages:

1) Isothermal expansion.

2) Adiabatic expansion

3) Isothermal compression.

4) Adiabatic compression.

Efficiency of heat = $\eta = \frac{\text{heat conveted into work}}{\text{heat taken from source}}$

$$\Rightarrow \eta = \frac{H_1 - H_2}{H_1} = 1 - \frac{H_2}{H_1}$$

For carnot engine,

$$\frac{H_2}{H_1} = \frac{T_2}{T_1}$$

$$\Rightarrow \eta = 1 - \frac{H_2}{H_1} = 1 - \frac{T_2}{T_1}$$

74. Define adiabatic process. Derive an expression for work done during adiabatic process.

Answer: The process during which there is no exchange of heat takes place between a system and its environment is known as an adiabatic process.

Adiabatic process: $PV^{\gamma} = K$

So, $P = KV^{-\gamma}$

Work done $= W = \int PdV$

$$\Rightarrow W = \int KV^{-\gamma}Dv$$

$$\Rightarrow W = K\times \left|\frac{V^{-\gamma+1}}{1-\gamma}\right|_{V_1}^{V_2}$$

$$\Rightarrow W = \frac{K}{1-\gamma} \times [\, V_2^{-\gamma+1} - V_1^{-\gamma+1}]$$

$$\Rightarrow W = \frac{1}{1-\gamma} \times [\, KV_2^{-\gamma+1} - KV_1^{-\gamma+1}]$$

$$\Rightarrow W = \frac{1}{1-\gamma} \times [\, P_2V_2^{\gamma}V_2^{-\gamma+1} - P_1V_1^{\gamma}V_1^{-\gamma+1}]$$

$$\Rightarrow W = \frac{P_2V_2 - P_1V_1}{1-\gamma}$$

15

Electric Charge And Electric Field

Short summary

What do we learn

Quick Revision

➢ *What is term 'Electrostatic'?*

Electrostatics is a branch of physics which deals with the *"study of forces, fields and charges or it deals with the study of charges at the rest."*

➢ *Applications of electrostatic*

1. Electrostatic loudspeakers.
2. Electrostatics spraying of paints and powder coating.
3. Xerox copying machine.
4. Design cathode ray tube.
5. In T.V. and radar.

➢ *Concept of frictional electricity*

"The electricity (i.e. transfer of electrons) that is produced due to friction is called frictional electricity."

- When we rub two neutral bodies, there will be some transfer of electrons from one body to the other due because of the frictional forces acting on them.

➢ *Important result on the basis of experiments -:*

- There are only two kinds of electric charges positive charge and negative charge.

- Like charges repel and unlike charges attracts each other.

➢ *Electric charge*

''Electric charge is an intrinsic property of elementary particle of matter which give rise to electric force between various objects.''

- It is the property due to which it (element) produce and experience the electric and magnetic field.

- it is represented by the symbol '**q**'. it is a scalar quantity & Its S.I. unit is Coulomb.

∗ Basically there are two types of electric charge: *+ve charge and -ve charge*

- Proton→ +ve & ele. → –ve charge
- Charge on 1 electron = **1.6×10^{-19}C**
- Like charges repell and unlike charges attracts.

➢ *Basic properties of electric charge*

1. Additivity
2. Quantization
3. Conservation

➢ *Additivity*

Additivity of electric charges means that the total charge of a system is the algebraic sum of all individual charges located at different points inside the system.

$$\boxed{q = q_1 + q_2 + q_3 + \dots + q_n}$$

➢ *Quantization*

The quantization of a physical quantity means it can change discontinuously to take anymore of only a discrete set of values.

$$\boxed{Q = ne}$$

$n = \pm 1, \pm 2, \pm 3, \dots\dots$

➢ *Conservation*

The law of conservation states that:

(A) The total charges of an isolated system remain constant.

(B) The electric charges can neither be created nor destroyed. It can only be transferred from one body to another.

➢ *Coulomb's law*

According to Coulomb, the force of attraction and repulsion between two stationary point charges is:

① Directly proportional to the product of the magnitude of two charges.

$$\boxed{F \propto q_1 \times q_2}$$

② Inversely proportional to the square of the distance between them.

$$\boxed{F \propto \frac{1}{r^2}}$$

Overall, it can be conclude that :

$$\boxed{F \propto \frac{q_1 \times q_2}{r^2}}$$

$$\Rightarrow \boxed{F = k\frac{q_1 \times q_2}{r^2}} \quad \text{Or} \quad \boxed{F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 \times q_2}{r^2}}$$

k = Electrostatic constant = $\frac{1}{4\pi\varepsilon_0}$

$k = 9 \times 10^9\ Nm^2C^{-2}$

➢ *1 coulomb charge is -:*

"If two equal charges separated by one meter experience a force of 9×10^9 N, *each charge has a magnitude of one coulomb."*

➢ *Limitations of coulomb's force*

① The electric charges must be at rest.

② The electric charges must be point charges.

③ The separation distance between the charges must be greater than the nuclear size.

➢ *Dielectric constant*

The ratio $\frac{\varepsilon}{\varepsilon_0}$ of the permittivity of the vacuum to the permittivity of medium is called ‘Relative permittivity’ (ε_r) or Dielectric constant.

$$\boxed{\frac{F_{vac}}{F_{med}} = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r = k}$$

➢ *Vector form of coulomb law*

$$\boxed{F_{12} = -\frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r^2} \times \hat{r}_{21}}$$

$$\boxed{F_{21} = -\frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r^2} \times \hat{r}_{12}}$$

NOTE: The positive sign indicates that the force is repulsive and the negative sign indicates that the force is attractive.

➢ *Principle of Superposition*

When there are more than two point charges experience force, we use the principle of superposition to calculate total force.

The principle of superposition states that “*when a number of charges are interacting then the total force on a given charge is the vector sum of the forces exerted by each charge.*”

$$\boxed{F_{net} = F_{12} + F_{13} + F_{14} + \dots}$$

➢ *Electric field*

The electric field E at a point is defined as “the force experienced by a positive test charge placed at that point without disturbing the position of source charge.”

Test charge: Point charge which experiences the electric field.

Source charge: Point charge which produces the electric field.

Mathematically, $\boxed{E = \frac{F}{q_0}}$

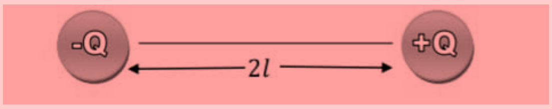
- Electric field is a vector quantity.
- Direction of **E** is same as that of **F**.
- S.I. Unit is Newton / Coulomb.
- Dimensional formula is $[M^1 L^1 T^{-3} A^{-1}]$.
- According to the principle of superposition, total field at point P due to all charges is the vector sum of all fields.

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 + \mathbf{E}_3 + \dots$$

$$\mathbf{E} = k\sum_{i=1}^{N} \frac{q_i\,\hat{\mathbf{r}}_i}{r_i^2}$$

➢ *Electric dipole*

Two charges equal in magnitude but opposite in (sign) nature separated by a small distance, this system is called Electric Dipole.



➢ More about Electric dipole

Dipole moment –: Product of the charge and the distance between two charges is termed as **Dipole moment**.

$$\boxed{p = q.\ 2l}$$

- It is denoted by p.
- p is a vector quantity.
- Its S.I. Unit is Coulomb × meter (C.m).
- Net charge is zero in the dipole.
- Net Electric field due to dipole is ≠ 0.
- All distance are measured from mid-point of the dipole.

➢ Electric field due to dipole

Electric field due to a dipole at an **axial point** = E_{axial}

$$\boxed{E_{axial} = \frac{2p}{4\pi\varepsilon_0 . r^3}} \quad \text{Or} \quad \boxed{E_{axial} = \frac{2kp}{r^3}}$$

Electric field due to a dipole at an **equatorial point** = $E_{equautorial}$

$$\boxed{E_{axial} = \frac{p}{4\pi\varepsilon_0 . r^3}} \quad \text{Or} \quad \boxed{E_{axial} = \frac{kp}{r^3}}$$

➢ Torque

"Torque is the rotational analog of force."

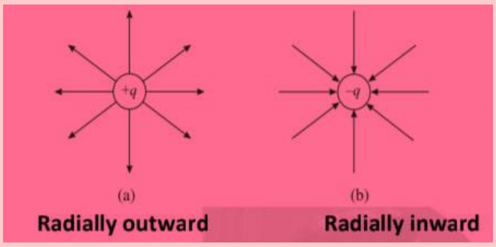
$$\boxed{\tau = pE \sin\theta} \quad \Rightarrow \quad \boxed{\tau = p \times E}$$

When θ = 0°, the torque is zero, which is minimum.
When θ = 90°, the torque is ***pE***, which is maximum.

➢ Electric lines of force (field lines)

The electric field lines not exist in real, they are just imaginary lines which tell us about the intensity of electric field.

∗ Direction of field lines of positive charge and negative charge is mentioned as-:



➢ Properties of field lines

① Two field lines can never be intersect.
② Field lines are always perpendicular to the tangent.
③ Number of field lines is directly proportional to the amount of charge.
④ Field lines contract longitudinally during attraction between unlike charges.
⑤ Field lines exert lateral pressure during repulsion between two like charges.
⑥ A tangent at any point on field line gives the direction of electric field at that point.
⑦ For a dipole, field lines start from the positive charge and terminate on the negative charge.

➢ *Electric flux*

Total number of field lines crossing per unit area, it is called Electric flux.

- Electric flux is denoted by ϕ.

- Mathematically it can be written as the dot product of electric field vector and area vector.

$$\boxed{\phi = \vec{E}.\vec{A}}$$

➢ *Guass law*

Gauss law states that “total electric flux over a closed surface is equal to $1/\varepsilon_0$ times the total charge inside the Gaussian surface.”

$$\boxed{\emptyset_E = q/\varepsilon_0}$$

- The spherical surface of the sphere is referred to as **Gaussian surface**.

- Gaussian surface is an imaginary mathematical surface.

- Gauss’ law is a useful tool for determining the electric field.

➢ *Electric field due to a point charge*

$$\boxed{E = \frac{q}{4\pi\varepsilon_0 r^2}}$$

➢ *Electric field due to a long line charge*

$$\boxed{E = \frac{\sigma_l}{2\pi\varepsilon_0 r}}$$

$\{\sigma_l$ = density = charge/length$\}$

➢ *Electric field due to uniformly charged spherical shell*

(a) Field at an external point:

$$\boxed{E = \frac{Q}{4\pi\varepsilon_0 r^2}}$$

(b) Electric field at internal point:

$$\boxed{E = 0 \Rightarrow Q = 0}$$

➢ *Electric field due to a plane sheet of charge*

$$\boxed{E = \frac{\sigma}{2\varepsilon_0}}$$

➢ *Van De Graff generator*

It is an Electrostatic generator, used for building up extremely high potential differences in the order of few million.

* **It works on two principles:**

1. Corona discharge.
2. Accumulation of charge on the outer sphere.

Question - Answer

① MCQs

1. **What is the process by which electrons are transferred between two objects due to rubbing?**

(A) Ionization (B) Induction
(C) Conduction (D) Frictional Charging

Answer: **(D) Frictional Charging**

2. If two objects are rubbed together and one becomes positively charged, what can be said about the charge on the other object?

(A) It becomes positively charged
(B) It becomes negatively charged
(C) It remains neutral
(D) It loses mass

Answer: **(B) It becomes negatively charged**

3. **The SI unit of electric charge is:**

(A) Coulomb (B) Ampere (C) Volt (D) Ohm

Answer: **(A) Coulomb**

4. **If two positively charged objects are brought close together, what is the nature of the force between them?**

(A) Attractive (B) Repulsive (C) Neutral (D) No force

Answer: **(B) Repulsive**

5. **What is the principle of conservation of charge?**

(A) Charge is always created in pairs
(B) The total electric charge in an isolated system remains constant
(C) Charge can be destroyed by certain processes
(D) Charge is proportional to mass

Answer: **(B) The total electric charge in an isolated system remains constant**

6. **If an object gains 2.5 x 10^{-6} C of charge, how many excess electrons does it acquire? (Elementary charge e =1.6×10^{-19}C)**

(A) 1.56×10^{13} (B) 1.56×10^{6} (C) 1.56×10^{2} (D) 1.56×10^{-13}

Answer: **(A) 1.56×10^{13}**

7. **The quantisation of charge indicates that**

(A) Charge, which is a fraction of charge on an electron, is not possible

(B) charge cannot be destroyed

(C) Charge exists on particles

(D) There exists a minimum permissible charge on a particle

Answer: **(A) Charge, which is a fraction of charge on an electron, is not possible**

8. **Coulomb's Law describes the force between two charges as:**

(A) Inversely proportional to the product of charges

(B) Directly proportional to the square of the distance between charges

(C) Directly proportional to the product of charges

(D) Inversely proportional to the square of the distance between charges

Answer: **(C) Directly proportional to the product of charges**

9. **If the distance between two charges is doubled, and the charges remain the same, how does the electric force between them change according to Coulomb's Law?**

(A) It becomes half (B) It becomes double

(C) It becomes four times (D) It remains the same

Answer: **(A) It becomes half**

10. **Coulomb's Law is valid for charges that are:**

(A) Stationary (B) Moving with constant velocity

(C) Accelerating (D) Both A and B

Answer: **(A) Stationary**

11. The force between two charges is 36 N. If the distance between them is tripled, what is the new force?

(A) 12 N (B) 18 N (C) 4 N (D) 6 N

Answer: (C) 4 N

12. If three charges are arranged in a line, the net force on the middle charge due to the other two charges is:

(A) Zero (B) Maximum (C) Minimum (D) Indeterminate

Answer: (A) Zero

13. In the vector form of Coulomb's Law, the unit vector $\hat{r}$ represents:

(A) The direction of the force
(B) The direction of the electric field
(C) The unit vector along the line joining the charges
(D) The unit vector perpendicular to the line joining the charges

Answer: (C) The unit vector along the line joining the charges

14. Which of the following is not scalar quantity in the context of electric charges?

(A) Electric Force (B) Electric charge
(C) Electric Field (D) Electric Current

Answer: (B) Electric charge

15. Which one of the following laws, does not pertain to electrostatics?

(A) Coulomb's law (B) Gauss's law
(C) Ampere's law (D) Law of conservation of charge

Answer: (C) Ampere's law **[PYQ NIOS April 2022]**

16. Two point charges, +Q and -2Q, are placed 3 meters apart. What is the net electric force between them?

(A) 1/9 times the force between two +Q charges
(B) 2/3 times the force between two +Q charges
(C) 1/3 times the force between two +Q charges
(D) 3 times the force between two +Q charges

Answer: **(A) 1/9 times the force between two +Q charges**

17. The dielectric constant of a material is a measure of its:

(A) Conductivity (B) Polarizability

(C) Charge density (D) Resistance

Answer: **(B) Polarizability**

18. What is the dielectric constant of a metal?

(A) -1 (B) 0 (C)1 (D) Infinite

Answer: **(D) Infinite**

19. If a positive test charge is placed in an electric field, in which direction does it experience a force?

(A) Opposite to the field direction

(B) Perpendicular to the field direction

(C) Along the field direction

(D) Independent of the field direction

Answer: **(C) Along the field direction**

20. The electric field inside a conductor in electrostatic equilibrium is:

(A) Zero (B) Maximum (C) Uniform (D) Variable

Answer: **(A) Zero**

21. The electric field at a point due to a dipole is zero at:

(A) The midpoint of the dipole

(B) Infinity

(C) Both the midpoint and infinity

(D) Nowhere; the electric field is always present

Answer: **(B) Infinity**

22. In the electric field lines due to a positive point charge, the direction of the field lines represents the direction of:

(A) Force on a positive test charge

(B) Force on a negative test charge

(C) Electric potential energy
(D) Electric flux

Answer: **(A) Force on a positive test charge**

23. **The electric field lines due to an electric dipole:**

(A) Are straight lines
(B) Are circles
(C) Are parabolas
(D) Do not follow a specific pattern

Answer: **(B) Are circles**

24. **In the electric field lines due to an electric dipole, the equipotential surfaces are:**

(A) Spheres
(B) Planes perpendicular to the dipole axis
(C) Cylinders
(D) Planes parallel to the dipole axis

Answer: **(D) Planes parallel to the dipole axis**

25. **What principle is utilized in the working of a Van de Graaff generator?**

(A) Induction
(B) Faraday's Law of Electromagnetic Induction
(C) Electromagnetic Induction
(D) Electrostatic Induction

Answer: **(C) Electrostatic Induction**

② Complete the sentence using an appropriate word

26. **point charges, NC^{-1} and C – m, polarity of charges, electric field, the direction of field lines**

(a) ---------- gives the information on field strength, direction, and nature of the charge.

(b) If the sizes of charged bodies are very small compared to the distances between them, we treat them as ------------.

(c) The property which differentiates two kinds of charges is called -----------.

(d) A charge particle is free to move in an electric field. It will travel along -------.

(e) SI unit of electric field intensity ----------- and electric dipole moment ---------.

Answer: (a) electric field (b) point charges (c) polarity of charges (d) the direction of field lines (e) NC^{-1} and C - m

③ Fill in the blanks:

27.

(a) The electric field near a conducting surface having a uniform surface charge density σ is given by ----------.

(b) Gauss's theorem states that total ---------- through a ---------- Surface is equal to $1/\varepsilon_0$ times the net charge enclosed by the surface.

(c) A system containing two equal charges separated by a finite distance is called an ----------.

(d) 1 coulomb charge is the charge which when placed at a distance of ---------- from an equal and similar charge in vacuum will repel it with a force of ---------- N.

(e) The electric field lines appear to start from ---------- and to terminate at ---------- Charge.

Answer: (a) $\frac{\sigma}{\varepsilon_0}$, (b) flux, Gaussian (c) electric dipole (d) 1 meter, 9×10^9 (e) positive charge, negative charge

④ Match the following:

28. Match column I statement with the right statement of column II.

COLUMN I	COLUMN II
A. Electric charge	1. $M^{-1}L^{-3}T^{4}A^{2}$
B. Electric field strength	2. $MLT^{-3}A^{-1}$
C. Absolute permittivity	3. $MT^{-3}A^{-1}$
D. Electric dipole	4. None

Answer: A – 4, B – 2, C – 1, D – 4

⑤True or false:

29. Electric charge is a scalar quantity.

⇒ False

30. Like charges attract each other, while opposite charges repel.

⇒ False

31. Coulomb's law describes the relationship between electric charge, distance, and force.

⇒ True

32. Electric field lines originate from positive charges and terminate on negative charges.

⇒ True

33. Conductors allow the easy flow of electric charge, while insulators do not.

⇒True

34. The unit of electric field is volts per meter (V/m).

⇒ True

35. Equipotential surfaces are always perpendicular to electric field lines.

⇒ True

36. Gauss's law is only applicable to closed surfaces.

⇒ True

37. The force between two charges is inversely proportional to the square of the distance between them.

⇒ True

38. Electric flux through a closed surface is proportional to the net charge enclosed by that surface.

⇒ True

39. The electric field due to a point charge is inversely proportional to the distance from the charge.

⇒True

40. The total charge of the isolated system is NOT conserved.

⇒ False

⑥ Very short type question answer (2 marks of each)

41. **Define electric charge quantization and its implications at the quantum level.**

Answer: Electric charge quantization refers to the discrete nature of charge, evident in elementary particles, demonstrating fundamental aspects of quantum physics.

42. **What do you mean by one Coulomb?**

Answer: 1 Coulomb refers to the charge on a body if it receives a force of either attraction or repulsion of 9×10^9N from another equal charge when they have a distance of 1m between them.

43. **State Coulomb's Law and discuss its applicability in describing the force between charged particles, emphasizing its dependence on distance and charge magnitude.**

Answer: Coulomb's Law states that the force between two charges is directly proportional to their product and inversely proportional to the square of the distance between them. It accurately describes electrostatic interactions.

44. Discuss the role of the electric constant (ε_0) in Coulomb's Law and its significance in differentiating between vacuum and other mediums.

Answer: The electric constant, ε_0, in Coulomb's Law accounts for the medium's influence on electric force. It distinguishes vacuum from other mediums, affecting the strength of interactions.

45. Discuss the experimental techniques used to verify Coulomb's Law at macroscopic and microscopic scales and their role in validating the fundamental nature of electric forces.

Answer: Experimental techniques, such as torsion balance and particle accelerators, verify Coulomb's Law at different scales, confirming the accuracy of its predictions and the fundamental nature of electric forces.

46. Explain the vector nature of Coulomb's Law and its impact on analyzing the net force in systems with multiple charges.

Answer: Coulomb's Law is a vector equation, considering both magnitude and direction of forces. It is essential for determining the net force in complex charge distributions.

$$\boxed{F_{12} = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1q_2}{r^2}\times\hat{r}_{21}}$$

47. Discuss the role of superposition principle in understanding the distribution of electric charge in complex systems.

Answer: The superposition principle enables the analysis of complex charge distributions by treating them as combinations of simpler configurations, facilitating solutions in electrostatics.

48. Define electric field intensity and explain its vector nature, highlighting its role in describing the force experienced by a test charge in an electric field.

Answer: Electric field intensity (E) is a vector representing the force experienced by a unit positive charge at a point in the field.

49. Define electric dipole moment. Give its S.I. unit. **[PYQ NIOS Jan 2021]**

Answer: Electric dipole moment (p) is the product of the magnitude of charge (q) and the separation (d) between charges in an electric dipole. Its SI unit is coulomb-meter (C·m).

50. Discuss the conditions for maximum and minimum potential energy of an electric dipole in an external electric field and their significance.

Answer: Maximum potential energy occurs at θ = 90°, while minimum occurs at θ = 0° or 180°. These positions signify unstable and stable equilibrium, respectively.

51. How does the principle of electric dipole moment apply to molecular structures in materials?

Answer: Electric dipole moment in materials arises from the separation of charges within molecules, influencing their electrical and chemical properties at the molecular level.

52. How will an electric dipole behave when placed in a non - uniform electric field? **[PYQ NIOS April 2022]**

Answer: In a non-uniform field, a dipole experiences both a net force and torque, causing translational and rotational motion, influencing its orientation.

53. Elaborate on the role of Gauss's law in analyzing complex charge distributions.

Answer: Gauss's law simplifies the calculation of electric fields in complex charge distributions by relating the electric flux to the enclosed charge.

54. Explain the phenomenon of electric polarization in dielectric materials and its impact on the overall electric field in the presence of an external field.

Answer: Electric polarization in dielectrics involves induced dipoles aligning with an external field, enhancing the overall electric field strength and influencing material properties.

55. Why can't two electric lines of force intersect each other?

Answer: This can be understood through an example. Let's imagine if they intersect, then at the place of contact, we can draw two tangents from it.

These two tangents are intended to depict two directions of electric field lines, which, at a given spot, is not achievable.

56. Explain the significance of equipotential surfaces in relation to electric field lines, emphasizing their mutual orthogonality and role in energy conservation.

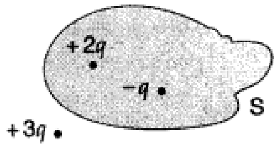
Answer: Equipotential surfaces are where electric potential is constant. Their mutual orthogonality with electric field lines ensures energy conservation, as work done moving along them is zero, aiding in analysis.

57. Explain the working principle of a Van de Graff generator, emphasizing the transfer of charge and the role of the belt and collector.

Answer: A Van de Graff generator operates by friction, transferring charge to a metal sphere via a belt and collector.

⑦ Short type question answer (3 marks of each)

58. **Figure shows three point charges, +2q, -q and + 3q. Two charges +2q and -q are enclosed within a surface 'S'. What is the electric flux due to this configuration through the surface 'S'**



Answer: Electric flux $= \oint_S \vec{E}.\vec{dS} = \frac{q_1}{\varepsilon_0}$

According to *Gauss's law*, $\phi = \oint_S \vec{E}.\vec{dS} = \frac{q_1}{\varepsilon_0}$

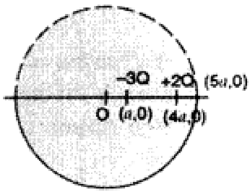
...where [q_1 is the total charge enclosed by the surface S

$$\phi = \frac{2q - q}{\varepsilon_0} = \frac{q}{\varepsilon_0} \quad \therefore \quad \text{Electric flux, } \phi = \frac{q}{\varepsilon_0}$$

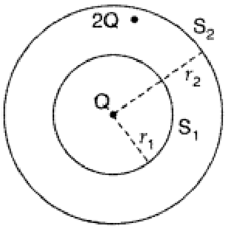
59. **Two charges of magnitudes -3Q and + 2Q are located at points (a, 0) and (4a, 0) respectively. What is the electric flux due to these charges through a sphere of radius '5a' with its centre at the origin?**

Answer:

$$\text{Flux} = \frac{\text{Charge enclosed}}{\varepsilon_0}$$
$$= \frac{+2Q - 3Q}{\varepsilon_0}$$
$$= \frac{-Q}{\varepsilon_0}$$



60. **A sphere S_1 of radius r_1 encloses a net charge Q. If there is another concentric sphere S_2 of radius r_2 (r_2 > r,) enclosing charge 2Q, find the ratio of the electric flux through S_1 and S_2. How will the electric flux through sphere S_1 change if a medium of dielectric constant K is introduced in the space inside S_2 in place of air?**



Answer:

$$\text{Flux through } S_1(\phi_1) = \frac{Q}{\epsilon_0} \qquad \ldots(i)$$

$$\text{Flux through } S_2(\phi_2) = \frac{Q + 2Q}{\epsilon_0} = \frac{3Q}{\epsilon_0} \qquad \ldots(ii)$$

$$\therefore \quad \text{Ratio of flux} = \frac{\phi_1}{\phi_2} = \frac{Q/\epsilon_0}{3Q/\epsilon_0} = \frac{1}{3}$$

61. **What is the force between two small charged spheres having charges of 2 × 10^{-7} C and 3 × 10^{-7} C placed 30 cm apart in air?**

Answer: Repulsive force of magnitude 6 × 10^{-3} N

Charge on the first sphere, $q_1 = 2 \times 10^{-7}$

Charge on the second sphere, $q_2 = 3 \times 10^{-7}$

Distance between the spheres, r = 30 cm = 0.3 m

Electrostatic force between the spheres is given by $\mathbf{F} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 \times q_2}{r^2}$

$$\Rightarrow F = \frac{9 \times 10^9 \times 2 \times 10^{-7} \times 3 \times 10^{-7}}{(0.3)^2} = 6 \times 10^{-3} \text{ N}$$

The charges are of same nature. Hence, force between them will be repulsive.

62. Define electric flux and discuss its importance in Gauss's Law, including the expression relating flux to the enclosed charge.

Answer: Electric flux (Φ) is the surface integral of the electric field vector over a closed surface.

In Gauss's Law, it is crucial for understanding the relationship between the electric field and the enclosed charge within a closed surface.

The expression for Gauss's Law is: $\emptyset = \int \vec{E}.\, d\,\vec{A}$

This integral is equal to the total charge enclosed (Q) divided by the electric constant (ε_0): $\emptyset = \frac{q}{\varepsilon_0}$

Gauss's Law provides a powerful method for calculating electric fields using symmetry and simplifies calculations for systems with high symmetry.

63. A Uniformly Charged Conducting Sphere of 2.4m Diameter Has a Surface Charge Density of 80µC/m^2.Find the Charge on the Sphere.

Answer: given → Diameter of the sphere, d = 2.4 m ⇒ r = 1.2 m

Surface density = σ = 80µC/m^2 = 80×10^{-6} C/m^2

To find → Total charge on the surface of the sphere,

Q = Charge density × Surface area

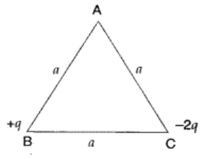
$$\Rightarrow Q = \sigma \times 4\pi r^2 = 80 \times 10^{-6} \times 4 \times 3.14 \times (1.2)^2$$

$$\Rightarrow Q = 1.447 \times 10^{-3} \text{ C}$$

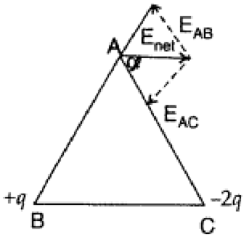
Therefore, the charge on the sphere is found to be 1.447×10^{-3} C

⑧Long type question answer [4 marks each]

64. **Two point charges + q and -2q are placed at the vertices 'B' and 'C' of an equilateral triangle ABC of side as given in the fig. Obtain the expression for (i) magnitude (ii) the direction of the resultant electric field at the vertex A due to these two charges.**



Answer: (*i*) **Magnitude,**



$$|\vec{E}_{AB}| = \frac{1}{4\pi\epsilon_0}\frac{q}{a^2} = E$$

$$|\vec{E}_{AC}| = \frac{1}{4\pi\epsilon_0}\frac{2q}{a^2} = 2E$$

$$E_{net} = \sqrt{(2E)^2+E^2+2\times 2E\times E\times\left(-\frac{1}{2}\right)}$$

$$\left[\because \cos 120° = -\frac{1}{2}\right]$$

$$= \sqrt{4E^2+E^2-2E^2}$$

$$= \sqrt{3E^2} = E\sqrt{3} = \frac{1}{4\pi\epsilon_0}\frac{q\sqrt{3}}{a^2}$$

(*ii*) **Direction** of resultant electric field at vertex A,

$$\tan\alpha = \frac{E_{AB}\sin 120°}{E_{AC}+E_{AB}\cos 120°}$$

$$= \frac{E\times\frac{\sqrt{3}}{2}}{2E+E\times\left(\frac{-1}{2}\right)} = \frac{\frac{E\times\sqrt{3}}{2}}{\frac{3E}{2}} = \frac{\sqrt{3}}{3}$$

$$= \frac{1}{\sqrt{3}} = \tan 30°$$

$$\therefore \quad \alpha = 30° \text{ (with side AC)}$$

65. **What are electric field lines? State their three properties. Draw electric field lines for (a) single positive point charge; and (b) electric dipole.**

[PYQ NIOS Oct 2021]

Answer: **Electric field lines:** An electric field line is an imaginary line or curve drawn from a point of an electric field such that tangent to it (at any point) gives the direction of the electric field at that point.

Properties of electric field lines:

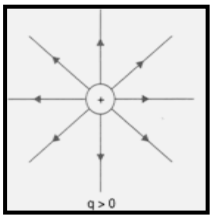
1. Electric field lines starting from positive charge and terminating at a negative charge.

2. The number of field lines that start or end at a charge is directly proportional to the magnitude of the charge.

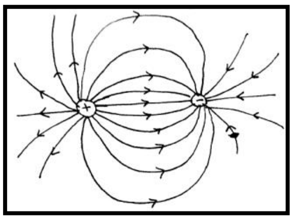
3. Two lines can never be intersect with each other.

Diagrams to show electric field lines for

(a) single positive charge –:



(b) Electric dipole –:



66. **(a) Define electric field at a point.**

(b) For finding electric field at a point we take the test charge $q_0 \to 0$. Why ?

[PYQ NIOS Oct 2022]

Answer: (a)The electric field E at a point is defined as “the force experienced by a positive test charge placed at that point without disturbing the position of source charge.”

(b) Electric fields are produced by electric charge distributions. Any test charge placed in an electric field will produce or be associated with its own electric field. This field will act on the original charge distribution to change the degree or angle of the polarizations of the charges, and this results in a change in the original electric field.

The smaller the test charge, the smaller the change in polarization of the charge distribution at issue. The closer the test charge is to the charge distribution, the bigger the problem.

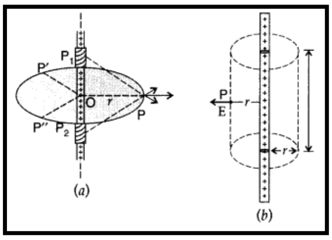
67. **A thin straight infinitely long conducting wire having charge density X is enclosed by a cylindrical surface of radius r and length l, its axis coinciding with the length of the wire. Find the expression for the electric flux through the surface of the cylinder.**

Answer: Since the field is everywhere radial, flux through the two ends of the cylindrical Gaussian surface is zero. At the cylindrical part of the surface, E is normal to the surface at every point, and its magnitude is constant, since it depends only on r. The surface area of the curved part is 2πrl, where l is the length of the cylinder.

Flux through the Gaussian surface = Flux through the curved cylindrical part of the surface is zero.

At the cylindrical part of the surface, E is normal to the surface at every point, and its magnitude is constant, since at every point, and its magnitude is constant, since it depends only on r. The surface area of the cylinder.

Flux through the Gaussian surface = Flux through the curved cylindrical part of the surface = E × 2πrl



(a) Electric field due to an infinitely long thin straight wire is radial.
(b) The Gaussian surface for a long thin wire of uniform linear charge density,
The surface includes charge equal to λl.
Gauss's law then gives

$$E \times 2\pi r l = \lambda l / \varepsilon_0$$

$$i.e. \quad \boxed{E = \frac{\lambda}{2\pi\varepsilon_0 r}}$$

68. **A charge +Q, is uniformly distributed within a sphere of radius R. Find the electric field, due to this charge distribution, at a point distant r from the centre of the sphere where :**

(i) 0 < r < R and
(ii) r > R

Answer: we have

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}, \text{ for a point charge}$$

Now (volume) charge density

$$\rho = \frac{Q}{\left(\frac{4\pi}{3}R^3\right)}$$

(*i*) ∴ Charge contained within a sphere of radius *r*, $(0 < r < R)$

$$Q' = \rho . \frac{4\pi}{3} . r^3 = \frac{Q}{\left(\frac{4\pi}{3} R^3\right)} \times \frac{4\pi}{3} . r^3 = Q \frac{r^3}{R^3}$$

∴ Electric Field

$$E = \frac{1}{4\pi\varepsilon_0} \frac{Q'}{r^2} = \left(\frac{1}{4\pi\varepsilon_0 r^2}\right) \times (Q) \frac{r^3}{R^3} = \left(\frac{1}{4\pi\varepsilon_0} . \frac{Q}{R^3} . r\right)$$

$$= \frac{1}{4\pi\varepsilon_0} \frac{Qr}{R^3}$$

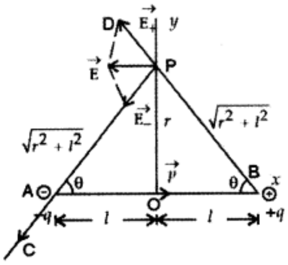
(*ii*) For $r > R$

Electric field due to a point charge (assumed to be kept at centre) at distance '*r*' :

$$E = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r^2}$$

⑨Very Long type question answer [5 marks each]

69. Derive the expression for electric field at a point on the equatorial line of an electric dipole.



Answer:

Electric field intensity at P due to +q charge is

$$\vec{E}_+ = \frac{1}{4\pi\varepsilon_0} \frac{q}{BP^2} \text{ along PD}$$

$$= \frac{1}{4\pi\varepsilon_0} \frac{q}{(r^2 + l^2)} \qquad \text{along PD} \ldots(i)$$

Electric field intensity at P due to -q charge is,

$$\vec{E}_- = \frac{1}{4\pi\varepsilon_0} \frac{q}{AP^2} \text{ along PC}$$

$$= \frac{1}{4\pi\varepsilon_0} \frac{q}{(r^2 + l^2)} \qquad \text{along PC} \ldots(ii)$$

From (*i*) and (*ii*), $|\vec{E}_+| = |\vec{E}_-| = \frac{1}{4\pi\varepsilon_0} \frac{q}{(r^2 + l^2)}$ ...(*iii*)

Net electric field intensity due to the electric dipole at point P

$$\therefore \quad E = \sqrt{E_+^2 + E_-^2 + 2E_+E_-\cos 2\theta}$$

$$\Rightarrow \quad E = \sqrt{E_+^2 + E_-^2 + 2E_+^2\cos 2\theta} \qquad (\because E_- = E_+)$$

$$\Rightarrow \quad E = \sqrt{2E_+^2 + 2E_+^2\cos 2\theta}$$

$$\Rightarrow \quad E = \sqrt{2E_+^2(1 + \cos 2\theta)}$$

$$\Rightarrow \quad E = \sqrt{2E_+^2\, 2\cos^2\theta} \qquad (\because 1 + \cos 2\theta = 2\cos^2\theta)$$

$$\therefore \quad E = 2E_+ \cos\theta = 2 \times \frac{1}{4\pi\varepsilon_0}\frac{q}{(r^2 + l^2)} \cos\theta$$

[Using equation (*iii*)]

Now from ΔOAP, $\cos\theta = \frac{l}{\sqrt{r^2 + l^2}}$

$$E = 2 \times \frac{1}{4\pi\varepsilon_0}\frac{q}{(r^2 + l^2)} \times \frac{l}{(r^2 + l^2)^{1/2}}$$

$$\Rightarrow \quad E = \frac{q \times 2l}{4\pi\varepsilon_0(r^2 + l^2)^{3/2}}$$

Since $q \times 2l = p$ ...(p is dipole moment)

$$E = \frac{p}{4\pi\varepsilon_0(r^2 + l^2)^{3/2}} \quad \text{along } (-)x\text{-axis}$$

If $l << r$ *i.e.* dipole is short, then l^2 can be neglected as compared to r^2

Hence $\boxed{E = \frac{p}{4\pi\varepsilon_0 r^3}}$ along $(-)x$-axis

70. **(a) Take a random electrostatic field arrangement as an example. A small test charge is positioned at the configuration’s null point or the location where E = 0. Show that the test charge’s equilibrium is inherently unstable.**

(b) Verify this result using the basic arrangement of two charges with the same magnitude and sign spaced apart.

Answer: (a) Let’s start by assuming that the little test charge positioned at the null point of the setup is stable and in equilibrium.

In order for the equilibrium to remain stable, the test charge must only move very slightly.

The charge will return to the null point in any direction because there will be surrounding it are tremendous restoring powers.

This shows even more strongly that all electric lines of force acting near the null point are toward the specified null point and inward.

However, according to Gauss’s law, the net electric flow through a chargeless surface enclosed is equal to zero. This fact defies the presumption that we had commenced with. In light of this, it may be said that the balance of the test charge must be unstable.

(b) The null point occurs to be at the midpoint of the line connecting these two charges when we take into account this configuration setup with two charges of the same sign and magnitude arranged at a specific distance apart.

According to the presumption made before, when the test charge is positioned at this midpoint, it will encounter substantial restoring forces as it tries to move itself.

However, because there is no restoring force along the normal to the line taken into account, the test charge is pulled off when it tries to displace in a direction normal to the line connecting the two charges.

The assumption is further challenged in this situation, since stable equilibrium prioritizes restoring force in all directions.

71. A hollow charged conductor has a tiny hole cut into its surface. Show that the electric field in the hole is $\left[\frac{\sigma}{2\varepsilon_0}\right]\hat{n}$, where $\hat{n}$ is the unit vector in the outward normal direction, and σ is the surface charge density near the hole.

Answer: Let us consider a conductor with a cavity or a hole. Electric field inside the cavity is zero. Let E is the electric field just outside the conductor, q is the electric charge, $\boldsymbol{\sigma}$ is the charge density, and $\boldsymbol{\varepsilon_0}$ is the permittivity of free space.

Charge $|q| = \bar{\sigma} \times \bar{d}$

According to Gauss’s law,

$$\phi = \bar{E}\bar{d} = \frac{|q|}{\epsilon_0}$$

$$Eds = \frac{\bar{\sigma} \times \bar{d}}{\epsilon_0}$$

$$\therefore E = \frac{\sigma}{\epsilon_0}\hat{n}$$

Therefore, the electric field just outside the conductor is $\frac{\sigma}{\epsilon_0}\hat{n}$. This field is a superposition of field due to the cavity E^1 and the field due to the rest of the charged conductor E^1. These fields are equal and opposite inside the conductor, and equal in magnitude and direction outside the conductor.

$$\therefore E^1 + E^1 = E$$

$$E^1 = \frac{E}{2} = \frac{\sigma}{2\epsilon_0}\hat{n}$$

Therefore, the field due to the rest of the conductor is $\frac{\sigma}{\epsilon_0}\hat{n}$.

Hence proved.

72. Discuss the concept of an electric field and its significance. How is the electric field strength related to force experienced by a charged particle within it?

Answer:

Electric Field: The electric field at a point is defined as the force experienced by a positive test charge placed at that point, divided by the magnitude of the test charge.

Mathematically, this relationship is expressed as: E = qF

Where, E = electric field strength at the point,

F = force experienced by the test charge,

q = the magnitude of the test charge.

Significance of Electric Field:

- Describing Interactions: The electric field concept is crucial for understanding how charged objects interact with each other. It provides a way to quantitatively describe the influence a source charge has on the space around it, affecting other charges in its vicinity.
- Force Prediction: By knowing the electric field at a point, one can predict the force that a charged particle placed at that point will experience. This is

especially useful in practical applications, such as designing and understanding the behavior of electrical circuits and devices.

- Field Lines Visualization: Electric field lines help visualize the direction and intensity of the electric field. They radiate outward from positive charges and converge toward negative charges, providing a visual representation of the force a positive test charge would experience.

Relation Between Electric Field Strength and Force:

The relationship between electric field strength (E) and the force (F) experienced by a charged particle is given by Coulomb's Law:

$$F = E/q$$

This formula indicates that the force experienced by a charged particle is directly proportional to the electric field strength at its location and the magnitude of its charge. Essentially, the stronger the electric field, the greater the force exerted on a charged particle within that field.

In summary, the electric field is a fundamental concept that helps explain the forces between charged particles and is essential for understanding and predicting the behavior of charged objects in various physical scenarios.

14

Wave phenomena

Short summary

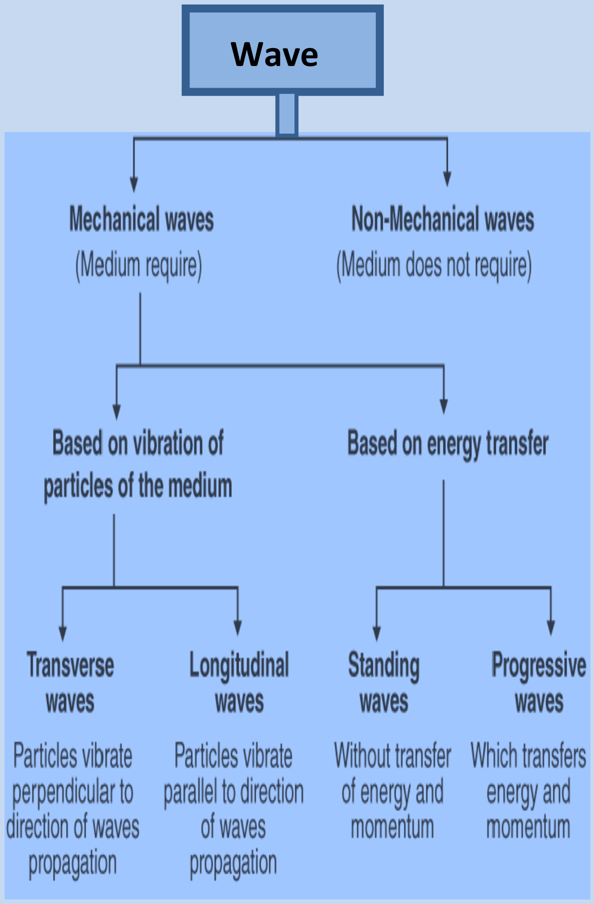
What do we learn

Quick Revision

➢ What is wave?

The propagating disturbance in the medium is called waves.
A wave is a disturbance which propagates energy and momentum from one place to the other without the transport of matter.

➢ Classification of wave



Wave

Mechanical waves (Medium require)

Non-Mechanical waves (Medium does not require)

Based on vibration of particles of the medium

Based on energy transfer

Transverse waves: Particles vibrate perpendicular to direction of waves propagation

Longitudinal waves: Particles vibrate parallel to direction of waves propagation

Standing waves: Without transfer of energy and momentum

Progressive waves: Which transfers energy and momentum

➢ Characteristics of wave

(i) **Elasticity:** So that particles can return to their mean position, after having been disturbed.

(ii) **Inertia:** So that particles can store energy and overshoot their mean position.

(iii) Minimum friction amongst the particles of the medium.

(iv) Uniform density of the medium.

➢ What is wave propagation

The term wave propagation refers to the movement of waves.

- All waves have *frequency*, *wavelength*, *amplitude*, and *wave speed*.
- Wave propagation speed quantifies how fast the wave travels.
- Waves carry energy, these do not transport mass.

➢ *Important terms*

1) Wavelength :

(i) It is the length of one wave.

(ii) Distance travelled by the wave in one time period is known as wavelength.

λ = Distance between two consecutive crests or troughs

(2) Frequency: Number of vibrations completed in one second.

$$\boxed{n = \nu = \frac{1}{T}}$$

(3) Time period: Time period of vibration of particle is defined as the time taken by the particle to complete one vibration about its mean position.

$$\boxed{\text{Time period} = \frac{1}{\text{frequency}}}$$

$$\boxed{T = \frac{1}{n}}$$

(4) Relation between velocity, frequency and wavelength:

$$\boxed{v = n\lambda}$$

➢ *Mechanical waves*

The waves which require medium for their propagation are called mechanical waves.

Example: Waves on string and spring, waves on water surface, sound waves, seismic waves.

➢ *Non – mechanical waves*

The waves which do not require medium for their propagation are called non-mechanical or electromagnetic waves.

Examples: Light, heat (Infrared), radio waves, γ-rays, X-rays *etc.*

➢ *Transverse waves*

The wave in which Particles of the medium execute simple harmonic motion about their mean position in a direction perpendicular to the direction of propagation of wave motion is called transverse wave.

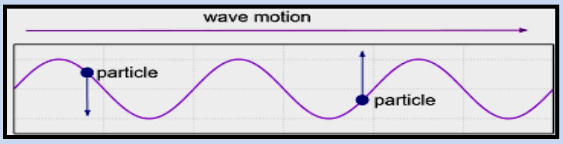
(i) It travels in the form of crests and troughs.

(ii) A crest is a portion of the medium which is raised temporarily.

(iii) A trough is a portion of the medium which is depressed temporarily.

(iv) Examples of transverse wave: Movement of string of a sitar, waves on the surface of water.

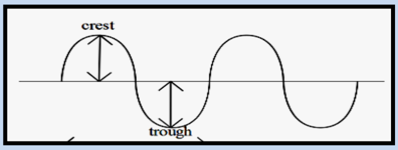
(v) Transverse waves cannot be transmitted into liquids and gases.



➢ Propagation of transverse waves

"Transverse wave propagates in the form of crest and trough."

Crest and Trough: The highest surface part of a wave is called the Crest, and the lowest part is the Trough.



Note:

(i) The propagation of transverse waves is possible only through solids and not through liquids or gases.

(ii) Only transverse waves can exhibit phenomenon of "POLARIZATION".

➢ Polarization

The vibration of the particles in a medium takes place in the same place; this is known as the plane of vibration or polarization.

While the wave moves along the string, all particles of the string are oscillating up and down about their respective equilibrium positions with the same time period (T) and amplitude (A). This wave remains progressive till it reaches the fixed end.

➢ Longitudinal waves

If the particles of a medium vibrate in the direction of wave motion the wave is called longitudinal.

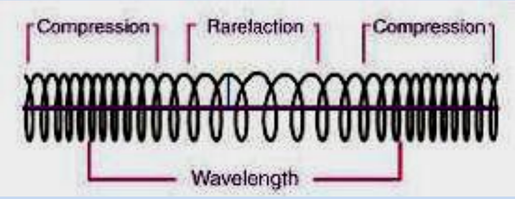
(i) It travels in the form of compression and rarefaction.

(ii) A compression (c) is a region of the medium in which particles are compressed.

(iii) A rarefaction (R) is a region of the medium in which particles are rarefied.

(iv) Examples sound waves travel through air in the form of longitudinal waves.

(v) These waves can be transmitted through solids, liquids and gases.



➢ Propagation of longi · waves

The propagation of energy is through a series of compression and rarefaction.

The particles of the medium undergo a series compression to rarefaction, which transmit energy in the direction as propagation of the energy.

➢ Progressive waves

1) These waves propagate in the forward direction of medium with a finite velocity.

2) Energy and momentum are transmitted in the direction of propagation of waves.

3) In progressive waves, equal changes in pressure and density occurs at all points of medium.

4) Various forms of progressive wave function.

(i) $y = A\sin(\omega t - kx)$

Where,
y = displacement,
A = amplitude,
ω = angular frequency,
n = frequency,
k = propagation constant,
T = time period,
λ = wave length,
v = wave velocity,
t = instantaneous time

(ii) $y = A\sin\left(\omega t - \frac{2\pi}{\lambda}x\right)$

(iii) $y = A\sin 2\pi\left(\frac{1}{T} - \frac{x}{\lambda}\right)$

(iv) $y = A\sin\frac{2\pi}{\lambda}(vt - x)$

(v) $y = A\sin\omega\left(t - \frac{x}{v}\right)$

➢ Some terms related to progressive waves

(i) **Wave number:** ($\overleftrightarrow{n}$)

The number of waves present in unit length.

$$\boxed{(\overleftrightarrow{n}) = \frac{1}{\lambda}}$$

(ii) **Propagation constant:** (*k*)

$$\boxed{k = \frac{\emptyset}{x}}$$

$$\boxed{k = \frac{\omega}{v} = \frac{\text{Angular velocity}}{\text{Wave velocity}}}$$

& $$\boxed{k = \frac{2\pi}{\lambda} = 2\pi\overleftrightarrow{n}}$$

(iii) **Wave velocity:** (*v*)

$$\boxed{v = \frac{\omega}{k} = n\lambda = \frac{\omega k}{2\pi}}$$

(iv) **Phase and phase difference:**

$$\boxed{\emptyset(x,t) = \frac{2\pi}{\lambda}(vt - x)}$$

(v) **Phase difference:**

$$= \boxed{\frac{2\pi}{T} \times \text{Time difference}}$$

(vi) **Phase difference:**

$$= \boxed{\frac{2\pi}{\lambda} \times \text{phase difference}}$$

⇒ Time difference = $\frac{T}{\lambda}$ × Path difference

➢ Velocity of sound (wave motion)

1) Speed of transverse wave motion:

(i) **On a stretched string:**

$$\boxed{v = \sqrt{\frac{T}{m}}}$$

T = Tension in the string;
m = Linear density of string (mass per unit length)

(ii) **In a solid body:**

$$\boxed{v = \sqrt{\frac{\eta}{\rho}}}$$

η = Modulus of rigidity;
ρ = Density of the material

2) Speed of longitudinal wave motion:

(i) **In a solid long bar:**

$$\boxed{v = \sqrt{\frac{Y}{\rho}}}$$

Y = Young's modulus;

(ii) **In a liquid medium:**

$$\boxed{v = \sqrt{\frac{k}{\rho}}}$$

k = Bulk modulus

(ii) **In gases:**

$$\boxed{v = \sqrt{\frac{k}{\rho}}}$$

➢ Velocity in elastic medium

Velocity of sound in any medium is:

$$\boxed{v = \sqrt{\frac{E}{\rho}}}$$

E = Elasticity of medium
ρ = density of medium

➢ Velocity in elastic medium

1) $v_{steel} > v_{water} > v_{air} \Rightarrow$ 5000 m/s > 1500 m/s > 330 m/s

➢ Newton's formula for velocity of sound in air

He assumed that propagation of sound is isothermal

$$v_{air} = \sqrt{\frac{k}{\rho}} = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{P}{\rho}}$$

As K = E_θ = P;
E_θ = Isothermal elasticity,
P = Pressure.
By calculation v_{air} = 279 m/sec.
However the experimental value of sound in air is 332 m/sec.

➢ Laplace correction

He modified that propagation of sound in air is adiabatic process.

$$v_{air} = \sqrt{\frac{k}{\rho}} = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{\gamma P}{\rho}}$$

As k = E_ϕ = γp = Adiabatic elasticity)
γ_{Air} = 1.41
$\Rightarrow v_{air}$ = 331.3 m/s

➢ Superposition of waves

If $\vec{y_1}$, $\vec{y_2}$, $\vec{y_3}$,……. are the displacements at a particular time at a particular position, due to individual waves, then the resultant displacement, $\vec{y} = \vec{y_1} + \vec{y_2} + \vec{y_3} + \ldots..$

This is known as principle of superposition.

➢ *Reflection and transmission of wave*

In transverse wave –:

- When reflection takes place from a denser medium, the wave undergoes a phase change of π, that is, it suffers a phase reversal.
- When reflection takes place from a rarer medium, no phase change takes place.

In longitudinal waves –:

- When reflection takes place from a denser medium, the longitudinal waves are reflected without change of type but with change in sign.
- When reflection from a rare medium, a longitudinal wave is reflected back without change of sign but with change of type.

➢ *Superposition of waves*

We make use of this principle to explain the phenomena of –:

~ Formation of beats and
~ Interference of waves,
~ Stationary or standing waves.

➢ *Beats*

The rise and fall in the intensity of sound due to the superimposition of two sound waves of slightly different frequencies travelling in the same direction is known as beats.

➢ *Standing or stationary waves*

When two sets of progressive wave trains of same type (both longitudinal or both transverse) having the same amplitude and same time period/frequency/wavelength travelling with same speed along the same straight line in opposite directions superimpose, a new set of waves are formed. These are called stationary waves or standing waves.

➢ *Interference of waves*

It is the superposition of two waves of same frequency, with constant phase difference.
There are two types of interference:

❶ **Constructive interference:** it is the phenomena of the superposition of two waves of same frequency, with zero phase difference.
❶ **Destructive interference:** it is the phenomena of superposition of two wave of same frequency with a phase difference of odd multiple of π radian.

➢ *Characteristics of musical sound*

① Pitch
② Loudness
③ Quality
④ Organ pipe

➢ *Pitch*

- The term pitch enables us to classify a note as ‘high’ or ‘low’.
- It is a subjective quantity which cannot be measured by an instrument.
- It depends on frequency not on intensity.

➢ *Loudness*

- Loudness refers to how loud or soft a sound to a listener.
- The loudness of sound is determined, in turn, by the intensity of the sound waves.

• *Quality*

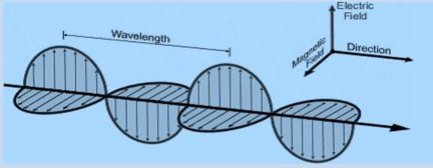
- The sound quality describes those characteristics of sound which allow the ear to distinguish sounds which have the same pitch and loudness.
- it is also known as ‘Timbre’ which is a general term for the distinguishable characteristics of a tone.

➢ *Organ pipe*

It is the simplest form of a wind instrument. “A wooden or metal pipe producing musical sound is known as organ pipe.”

➢ *Electromagnetic waves*

“Electromagnetic waves or EM waves are waves that are created as a result of vibrations between an electric field and a magnetic field.”



➢ *Electromagnetic spectrum*

“A suitable classification of EM waves is called the Electromagnetic Spectrum.”

The different parts of EM spectrum are as follows –:
①The low frequency radiation
②Radio waves
③Micro waves
④Infra – red waves
⑤Visible lights
⑥Ultra violet radiation
⑦X – rays
⑧Gamma – rays

➢ *Doppler effect*

According to Doppler’s effect whenever there is a relative motion between a source of sound and listener the apparent frequencies of sound heard by the listener is different from the actual frequency of sound emitted by the source.

Question - answer

① MCQs

1. Which of the following properties is characteristic of a transverse wave?

(a) Compression and rarefaction
(b) Longitudinal oscillation
(c) Crests and troughs
(d) Wavelength and frequency

Answer: (c) Crests and troughs

2. Which of the following is a longitudinal wave?

(a) Light wave (b) Sound wave
(c) Radio wave (d) Water wave

Answer: (b) Sound wave

3. In a transverse wave, what is the direction of particle oscillation compared to the direction of wave propagation?

(a) Parallel (b) Anti parallel
(c) Perpendicular (d) Tangential

Answer: (c) Perpendicular

4. Longitudinal waves are also known as:

(a) Pressure waves (b) Transverse waves
(c) Electromagnetic waves (d) Surface waves

Answer: (a) Pressure waves

5. Which term describes the number of oscillations per unit time and is measured in Hertz (Hz)?

(a) Amplitude (b) Wavelength
(c) Frequency (d) Period

Answer: (c) Frequency

6. What is the relationship between the speed (v), frequency (f), and wavelength (λ) of a wave?

(a) $v = f + \lambda$ (b) $v = \frac{f}{\lambda}$

(c) $v = f . \lambda$ (d) $v = f - \lambda$

Answer: (c) $v = f . \lambda$

7. What is the primary difference between mechanical and non-mechanical waves?

(a) Mechanical waves require a medium, while non-mechanical waves do not.

(b) Non-mechanical waves require a medium, while mechanical waves do not.

(c) Both require a medium for propagation.

(d) Neither requires a medium for propagation.

Answer: (a) Mechanical waves require a medium, while non-mechanical waves do not.

8. Sound waves travel faster in? **[PYQ NIOS Jan 2021]**

(a) solid (b) liquid (c) gas (d) Vacuum

Answer: (a) solid

9. The phenomenon of polarized sunglasses reducing glare is based on the principle of:

(a) Reflection (b) Refraction

(c) Interference (d) Polarization

Answer: (d) Polarization

10. If the frequency of a wave is 50 Hz and its period is 0.02 seconds, what is its wavelength?

(a) 1000 m (b) 10 m (c) 1 m (d) 0.5 m

Answer: (a) 1000 m

11. If the amplitude of a wave is doubled, what happens to its energy?

(a) It becomes half (b) It remains the same

(c) It becomes four times (d) It becomes double

Answer: (c) It becomes four times

12. When a wave passes from one medium to another, there is change of:

(a) frequency and velocity

(b) wavelength and velocity

(c) frequency and wavelength

(d) frequency, wavelength and velocity

Answer: (b) wavelength and velocity **[sample paper]**

13. The velocity of a wave is given by the product of its:

(a) Amplitude and frequency (b) Wavelength and frequency

(c) Amplitude and period (d) Wavelength and period

Answer: (b) Wavelength and frequency

14. If the phase difference between two waves is 2π, what is their relationship?

(a) In-phase (b) Out of phase

(c) Half-phase difference (d) Quarter-phase difference

Answer: (a) In-phase

15. The relation between phase difference (Ø) and path (Δ) is given by:

(A) $\varphi = \frac{2\pi}{\lambda}\Delta$ (B) $\Delta = \frac{2\pi}{\lambda}\varphi$

(C) $\varphi = 2\pi\lambda\Delta$ (D) $\Delta = 2\pi\lambda\varphi$

Answer: (A) $\varphi = \frac{2\pi}{\lambda}\Delta$ **[PYQ NIOS Jan 2021]**

16. If the wave number (k) of a wave increases, what happens to its wavelength (λ)?

(a) It decreases (b) It remains the same

(c) It increases (d) It becomes zero

Answer: (a) It decreases

17. **The displacement y of a particle in a medium can be expressed as $y = 10^{-6} \sin(100t + 20x + \pi/4)$ where t is in second and x in meter . The propagation constant of the wave is:** [sample paper]

(a) $100\ s^{-1}$ (b) 10^{-6} m (c) $20\ m^{-1}$ (d) $\pi/4$ rad

Answer: **(c) $20\ m^{-1}$**

18. **Angle between wave velocity and particle velocity of a longitudinal wave is:**

(a) 90° (b) 60° (c) 0° (d) 120°

Answer: **(c) 0°**

19. **Transverse progressive waves are characterised by:** [sample paper]

(a) compressions and rarefactions
(b) crests and troughs
(c) compressions and troughs
(d) crests and rarefactions

Answer: (b) crests and troughs

20. **The speed of sound in air depends on:**

(a) Temperature only (b) Pressure only
(c) Density only (d) Temperature, pressure, density

Answer: **(d) Temperature, pressure, density**

21. **The speed of sound in a medium is given by the equation, $v = \sqrt{\frac{B}{\rho}}$, where B is the bulk modulus and ρ is the density of the medium. What happens to the speed if the density increases?**

(a) It decreases (b) It remains the same
(c) It increases (d) It depends on the temperature

Answer: **(a) It decreases**

22. **Laplace's correction to Newton's formula takes into account the compressibility of air. This correction involves the:**

(a) Bulk modulus of air (b) Shear modulus of air
(c) Young's modulus of air (d) Rigidity modulus of air

Answer: **(a) Bulk modulus of air**

23. According to Newton's formula, the speed of sound in air is directly proportional to the:

(a) Square root of pressure (b) Square root of density
(c) Square root of temperature (d) Cube root of temperature

Answer: **(c) Square root of temperature**

24. In the superposition of waves, constructive interference occurs when the phase difference between the waves is:

(a) 0° (b) 180° (c) 90° (d) 360°

Answer: **(a) 0°**

25. In the superposition of waves, if the amplitudes of two waves are A and B, the minimum possible amplitude of the resulting wave is:

(a)A + B (b) A – B (c) AB (d) $A^2 – B^2$

Answer: **(b) A – B**

26. The pitch of a musical sound is primarily determined by its:

(a) Amplitude (b) Frequency (c) Harmonics (d) Overtones

Answer: **(b) Frequency**

27. The quality or color of a musical sound that allows us to distinguish between different musical instruments playing the same note is called:

(a) Amplitude (b) Frequency (c) Pitch (d) Timbre

Answer: **(d) Timbre**

28. The fundamental frequency is an open pipe is 120 Hz, then frequency of third harmonic is : **[PYQ NIOS Oct 2022]**

(a) 120 Hz (b) 360 Hz (c) 240 Hz (d) 480 Hz

Answer: **(b) 360 Hz**

29. **The ratio of the fundamental frequencies produced by an open pipe and a closed pipe of the same length is:** **[PYQ NIOS Oct 2022]**

(a) 1 : 4 (b) 4 : 1 (c) 1 : 2 (d) 2 : 1

Answer: **(d) 2 : 1**

30. **The Doppler Effect is utilized in various fields, including:**

(a) Weather forecasting (b) Medical imaging

(c) Wireless communication (d) All of the above

Answer: **(d) All of the above**

31. **Number of beats produced by two waves of $y_1 = a \sin 1000\pi t$, $y_2 = a \sin 1004\pi t$ is:** **[sample paper]**

(a) 0 (b) 1 (c) 4 (d) 8

Answer: **(c) 4**

32. **A source of sound of frequency 150 Hz is moving in a direction towards an observer with a velocity 110 ms^{-1}. If the velocity of sound is 330 ms^{-1}, the frequency of sound heard by the person is** **[sample paper]**

(a) 225 Hz (b) 200 Hz (c) 150 Hz (d) 100 Hz

Answer: **(a) 225 Hz**

33. **Two equations of two SHM $y = a \sin(\omega t - \alpha)$ and $y = a \cos(\omega t - \alpha)$. The phase difference between the two is**

(a) 0° (b) α° (c) 90° (d) 180°

Answer: **(c) 90°**

34. **The equation of simple harmonic motion $y = a \sin(2\pi t + \alpha)$ then its phase at time t = 0s is**

(a) $2\pi n t$ (b) α (c) $2\pi t + \alpha$ (d) $2\pi t$

Answer: **(b) α**

35. **For two systems to be in resonance, which of the following properties should be equal?**

(a) Wavelength (b) Frequency
(c) Amplitude (d) Wave velocity

Answer: **(b) Frequency**

② Complete the sentence using an appropriate word:

36. interference, period, frequency, amplitude, Lambda (λ), wavelength

(a) The maximum displacement of a particle from its equilibrium position in a wave is called **…………..**

(b) The time taken for one complete oscillation of a wave is referred to as the wave **……………**

(c) The speed of a wave is the product of its **…………..** and **………………**

(d) The phenomenon where two or more waves combine to form a new wave is known as wave **……………**

(e) **…………..** is the symbol used for wavelength.

Answer: (a) amplitude (b) period (c) frequency, wavelength (d) interference (e) Lambda (λ)

③ Fill in the blanks:

37.

(a) In a standing wave, the points with maximum displacement are called **…………..** and the points with zero displacement are called **…………..**

(b) The interference pattern formed by two waves with slightly different frequencies is known as **…………..** interference.

(c) The regions of maximum compression and rarefaction in a longitudinal wave are called **…………..**

(d) The speed of a longitudinal wave in a material depends on its **…………..** and **…………..**

(e) The **…………..** of a wave is the distance between two consecutive points that are in phase.

Answer: (a) Antinodes, nodes (b) beats (c) crests and troughs (d) elasticity, density, (e) wavelength

④ Match the following:

38. **Match column I statement with the right statement of column II.**

COLUMN I	COLUMN II
A. Standing wave	1. Hertz
B. Destructive interference	2. Maximum displacement from equilibrium
C. Phase	3. Transverse wave
D. Amplitude (unit)	4. Relationship between two waves at a given time
E. Wavelength	5. Waves canceling each other out

Answer: A – 3, B – 5, C – 4, D – 1, E - 2

⑤ True or false

39. The speed of a wave is determined by its frequency and amplitude.

⇒ False.

40. In a transverse wave, the particles oscillate parallel to the direction of wave propagation.

⇒ False.

41. The wavelength of a wave is the distance between two consecutive crests or troughs.

⇒ True.

42. The phenomenon of beats occurs when two waves of the same frequency interfere constructively.

⇒ False.

43. Longitudinal waves cannot exhibit interference patterns.

⇒ False.

44. The Doppler effect is the change in frequency or wavelength of a wave in relation to an observer moving relative to the source of the wave.

⇒ True.

45. Refraction of waves occurs only when transitioning from a denser medium to a less dense medium.

⇒ False.

46. Resonance is a phenomenon in which a wave matches the natural frequency of an object, resulting in increased amplitude.

⇒True.

47. Huygens' principle explains the behavior of both transverse and longitudinal waves.

⇒ True.

48. The frequency of a wave is inversely proportional to its wavelength.

⇒ False.

⑥ very short type question answer (2 marks of each)

49. Give answer of following question –:

a) A transverse wave travels along x-axis. The particles of the medium must move in which direction?

Answer: In the y – z plane or in plane perpendicular to x – axis.

b) Which property of the medium are responsible for propagation of waves through it ?

Answer: Properties of elasticity and inertia are responsible for propagation of waves.

50. Why does sound travel faster in iron than in water or air ?

Answer: Sound travel faster in iron or solids because iron or solid is highly elastic as compared to water (liquids) or air (gases).

51. Give one example of each of the following: **[PYQ NIOS April 2022]**

(i) Transverse wave

(ii) Longitudinal wave which we can sense but cannot see

Answer:

(i) Transverse Wave: Light Wave is an example of transverse wave. We can sensed light waves by our eyes, and we perceive them as colors, but we cannot see the actual oscillations because they are transverse to the direction of the wave.

(ii) Longitudinal Wave: Sound Wave is an example of longitudinal wave. We can sense sound waves through our ears, and we perceive them as sound, but we cannot see the compressions and rarefactions of air molecules.

52. Define wave number and angular wave number and give their S.I. units.

Answer:

Wave number: Wave number is the number of waves present in a unit distance of medium. It is denoted by k.

Angular wave number: Angular wave number or propagation constant is $2\pi/\lambda$. It represents phase change per unit path difference and denoted by $k = 2\pi/\lambda$.

S.I. unit of k is rad m^{-1}.

53. What is the role of elasticity in determining the speed of a longitudinal wave in a material?

Answer: The speed of a longitudinal wave in a material is directly proportional to the square root of its elasticity and inversely proportional to the square root of its density.

54. Define the term "frequency" and "amplitude" of a wave.

Answer: Frequency: Frequency is the number of oscillations or cycles of a wave per unit time.

Amplitude: Amplitude is the maximum displacement of particles from their equilibrium position in a wave.

55. Elaborate on the application of the Doppler effect in real-life situations.

Answer: The Doppler effect is used in radar systems, medical imaging, and astronomy to determine the velocity and distance of objects based on the shift in frequency of waves.

56. Compare and contrast the motion of particles in a transverse wave and a longitudinal wave.

Answer: In a transverse wave, particles move perpendicular to the wave direction, while in a longitudinal wave, particles move parallel to the wave direction.

57. Why longitudinal waves are called pressure waves?

Answer: Longitudinal waves are called pressure waves because the propagation of longitudinal waves through a medium consists of the variations in the volume and the pressure of the air, these variations in volume and air pressure result in the formation of compressions and rarefactions.

58. A hospital uses an ultrasonic scanner to locate tumors in a tissue. What is the wavelength of sound in the tissue in which the speed of sound is 1.7km /s ? The operating frequency of the scanner is 4.2 MHz .

Answer: The wavelength of sound in the tissue is given as:

$$\lambda = \frac{v}{V} = \frac{1.7 \times 10^{2}}{4.2 \times 10^{8}} = 4.1 \times 10^{-4}\ \text{m}$$

59. Give two cases in which there is no Doppler effect in sound?

Answer: The two circumstances in which there is no Doppler effect in sound (i.e. no change in frequency) are as follows: -

(1) When both the sound source and the listener are moving in the same direction and at the same speed.

(2) When one of the source listeners is in the circle's center and the other is travelling around it at a constant speed.

60. What type of mechanical waves can be produced (a) in gases, (b) in vacuum, (c) in water, and (d) on the surface of water?

Answer: (a) In gases, only longitudinal waves can be set up.

(b) In vacuum, mechanical waves cannot be set up at all.

(c) Inside the water, only longitudinal waves can be set up.

(d) On the surface of water, water ripples are set up which are almost transverse waves, set up under the action of surface tension of water.

61. How is propagation constant k related to wavelength of a travelling wave?

Answer: Propagation constant $k = \frac{2\pi}{\lambda}$

Where λ = wavelength of the given wave so k is inversely proportional to wavelength.

⑦Short type question answer (3 marks of each)

62. What are the basic differences between sound waves and light waves?

Answer: Basically, sound waves are mechanical waves which require a material medium for their propagation. Light waves are electromagnetic waves which do not need any material medium and can travel even through free space. Again, sound waves are longitudinal waves but light waves are transverse in nature. Moreover, frequency range of audible sound waves is from 20 Hz to 20 kHz, whereas frequency of visible light varies from 4.0×10^{14} Hz to 7.5×10^{14} Hz.

63. On what factors does the wave speed in a medium depend? Do longitudinal and transverse waves travel with same speed in a medium?

Answer: We know that for propagation of a wave through a given medium, the medium must possess inertia (or inertial mass) and elasticity. Therefore, elastic properties of the medium and linear mass density in case of a linear system and density for a bulk system determine the speed of wave propagation in that medium.

Generally, longitudinal and transverse waves travel with different speeds through same medium.

64. State two reasons, which were pointed out by Laplace for his correction to the formula for velocity of sound in air given by Newton.

[PYQ NIOS Oct. 2021]

Answer:

Inclusion of Gas Compression: Laplace considered the compression and rarefaction of air in sound wave propagation. Unlike Newton, who assumed an isothermal process (constant temperature), Laplace recognized that air undergoes adiabatic compression and expansion as sound waves pass through it. This led Laplace to incorporate the adiabatic bulk modulus of elasticity in his modified equation for the speed of sound.

Temperature Variation: Laplace also took into account the temperature variation in the air caused by the adiabatic compression and expansion. Newton's original formula did not consider changes in temperature during the sound wave's passage. Laplace's correction involved incorporating the adiabatic temperature changes in the equation, providing a more accurate description of how sound waves propagate through air.

In summary, Laplace's corrections accounted for the adiabatic nature of the compression and rarefaction of air, as well as the associated temperature changes, resulting in a more precise formula for the velocity of sound in air.

65. Distinguish between sound waves and radio waves of exactly the same frequency (say 10 kHz).

Answer: (a) Sound waves travel as longitudinal waves through a material medium only but radio waves travel as transverse electromagnetic waves without the need of any material medium.

(b) Speed of sound waves depends on nature of medium and is generally small (only 331 m s through air under STP conditions) but speed of radio waves is exceedingly large (3×10^8 m s in vacuum or air).

66. Show that for every 18C rise in temperature, the velocity of sound in air increases by 0.61 ms^{-1}.

[PYQ NIOS Oct 2022]

Answer: Let v_0 = velocity of sound at 0 °C or 273 K

v = velocity of sound at t °C or (273 + 1) K

We have, $v \propto \sqrt{T}$

$$\therefore \quad \frac{v}{v_0} = \sqrt{\frac{T}{T_0}}$$

$$\therefore \quad \frac{v}{v_0} = \sqrt{\frac{273+t}{273}} = \left(1+\frac{t}{273}\right)^{1/2}$$

$$\therefore \quad \frac{v}{v_0} = \sqrt{\left(1+\frac{t}{273}\right)} = \sqrt{(1+\alpha t)}$$

Where, $\alpha = \frac{1}{273}$

$$\therefore \quad v = v_0\,(1+\alpha t)^{1/2}$$

As α is very small, we can write

$$v = v_0\left(1+\frac{1}{2}\alpha t\right)$$

$$\therefore \quad v = v_0\left(1+\frac{t}{2\times 273}\right) \qquad \ldots\left(\because \alpha = \frac{1}{273}\right)$$

$$\therefore \quad v = v_0 + \left(\frac{v_0}{546}\right)t$$

$$\therefore \quad v = v_0 + \frac{332}{546}t \qquad \ldots(\because v_0 = 332\ \text{m/s})$$

$$\therefore \quad v = v_0 + 0.61t$$

67. Show that Doppler effect in sound is asymmetric?

Answer: The apparent frequency of sound when source is approaching the stationary listener (with velocity v^1) is not the same as the apparent frequency of sound when the listener is approaching the stationary source with a velocity v^1. This shows that Doppler Effect in sound is asymmetric.

Apparent frequency = $f^1 = \frac{V}{V-us} \times f$

This is when source approaches station any listener

V = Velocity of sound in air, u_s = Velocity of sound source = V_1

f^1 = Apparent frequency, f = Original frequency of sound

Apparent frequency $f^n = \frac{V+u_0}{V} \times f$

This is when listener approaching stationary source $f^n = \frac{V+V^1}{V} \times f$

Since $f' = f''$ (Hence Doppler effect is asymmetric)

68. **An organ pipe P_1 closed at one end vibrating in its first overtone and another pipe P_2 open at both the ends vibrating in its third overtone are in resonance with a given tuning fork. Find the ratio of length of P_1 and P_2?**

Answer: Length of pipe closed at one end for first overtone, $l_1 = \frac{3\pi}{4}$

Length of pipe closed at both ends for third overtone; $l_2 = \frac{3\pi}{4}$

π = wavelength

$$l_2 = \frac{4\pi}{2} = 2\pi \quad \Longrightarrow \quad \therefore \frac{l_1}{l_2} = \frac{\frac{3\pi}{4}}{2\pi} = \frac{3\pi}{4\times 2\pi} = \frac{3}{8} \quad \Longrightarrow \quad l_1 : l_2 = 3:8$$

69. **Explain why (or how):**

(a) In a sound wave, a displacement node is a pressure antinode and vice versa,

(b) Bats can ascertain distances, directions, nature, and sizes of the obstacles without any "eyes",

(c) A violin note and sitar note may have the same frequency, yet we can distinguish between the two notes,

Answer:

(a) A node is a point where the amplitude of vibration is the minimum and pressure is the maximum. On the other hand, an antinode is a point where the amplitude of vibration is the maximum and pressure is the minimum.

Therefore, a displacement node is nothing but a pressure antinode, and vice versa.

(b) Bats emit very high-frequency ultrasonic sound waves. These waves get reflected back toward them by obstacles. A bat receives a reflected wave (frequency) and estimates the distance, direction, nature, and size of an obstacle with the help of its brain senses.

(c) The overtones produced by a sitar and a violin, and the strengths of these overtones, are different. Hence, one can distinguish between the notes produced by a sitar and a violin even if they have the same frequency of vibration.

70. **The equation of a plane progressive wave is given by the equation y = 10 sin 2π (t - 0.005x) where y and x are in cm and t in seconds. Calculate the amplitude, frequency, Wave length and Velocity of the Wave.**

Answer: Here y = 10 sin 2π (t - 0.005x)

$$y = 10\sin\frac{2\pi}{200}(200t - x)$$

The equation of a travelling wave is given by

$$y = a\sin\frac{2\pi}{\lambda}(vt - x)$$

Comparing the equation (i) and (ii), we have

$\alpha = 10cm, \alpha = 200cm$ and v = 200 ms^{-1}

Now, $v = \frac{v}{\lambda} = \frac{200}{200} = 1H_z$

71. **The transverse oscillation of a string, clamped at both ends is given by: y = 0.06 sin $\left(\frac{2\pi}{3}x\right)$ cos (120 πt), where x and y are in cm and t is in second. The length of the string is 1.5 m and its mass is 3.0 × 10^{-2} kg.**

[PYQ NIOS Jan 2021]

(i) **Is the wave on the string travelling wave or stationary wave? Give reason for your answer.**

(ii) **Determine the tension in the string. (speed of wave in string = 180m/s)**

Answer:

(i) Travelling wave is given by y(x,t) = A sin(ωt ± kx + φ)

Standing wave is given by y(x,t) = A sin (kx) cos (ωt)

Hence, this is an example of standing wave.

(ii) speed of wave in string is given by

$$v = \sqrt{T/\mu} \Rightarrow T = v^2 m/l$$

$$T = \frac{180^2 \times 3\times 10^{-2}}{1.5} = 648 \text{ N}$$

⑧Long type question answers (5 marks of each)

72. **Explain the concept of wave motion. Discuss the characteristics that distinguish transverse waves from longitudinal waves.**

Answer:

Wave Motion:Wave motion is a phenomenon where energy is transmitted through the oscillation or disturbance of particles or fields in a medium without the physical transfer of matter. Waves carry energy from one point to another, and they exhibit various properties, including frequency, wavelength, amplitude, and velocity. Two common types of waves are transverse waves and longitudinal waves.

Characteristics Distinguishing Transverse Waves from Longitudinal Waves:

- Direction of Oscillation:

Transverse Waves: Oscillations are perpendicular to the direction of wave propagation. For example, in light waves, the electric and magnetic fields oscillate perpendicular to the direction of wave travel.

Longitudinal Waves: Oscillations occur parallel to the direction of wave propagation. In sound waves, air particles move back and forth along the same axis as the wave travels.

- Wave Shape:

Transverse Waves: The waveforms resemble crests and troughs, where the particles move up and down.

Longitudinal Waves: The waveforms exhibit compressions and rarefactions, where particles are compressed together and then spread apart.

- Polarization:

Transverse Waves: Transverse waves can be polarized, meaning the oscillations can be restricted to a specific plane.

Longitudinal Waves: Longitudinal waves cannot be easily polarized because the oscillations are along the direction of wave propagation.

- Propagation Mechanism:

Transverse Waves: Transverse waves are often associated with electromagnetic phenomena, such as light and radio waves.

Longitudinal Waves: Longitudinal waves commonly occur in mechanical waves, like sound waves in air or seismic waves in the Earth.

73. Elaborate on the principle of superposition in wave phenomena. How does constructive interference differ from destructive interference? Provide real-world examples.

Answer: Principle of Superposition:

The principle of superposition states that when two or more waves overlap in a medium, the resultant displacement at any point is the algebraic sum of the individual displacements caused by each wave. This principle applies to all types of waves, including electromagnetic waves, sound waves, and water waves.

Constructive Interference vs. Destructive Interference:

- Constructive Interference: it occurs when two waves have the same phase or a phase difference of multiples of a full wavelength.

Amplitude: The amplitudes of the overlapping waves add up, leading to an increase in the overall amplitude.

Example: In a concert hall, when two sound waves from different speakers reach a listener in phase, they interfere constructively, resulting in a louder and more audible sound at that location.

- Destructive Interference: it occurs when two waves have opposite phases or a phase difference of odd multiples of half a wavelength.

Amplitude: The amplitudes of the overlapping waves subtract from each other, leading to a decrease in the overall amplitude.

Example: Noise-canceling headphones use destructive interference by generating sound waves with the same amplitude but opposite phase to incoming noise, effectively reducing or canceling out the noise perceived by the listener.

74. Explain the role of phase in wave motion and how phase difference affects interference. Provide examples to illustrate the concepts.

Answer: Role of Phase in Wave Motion: Phase in wave motion refers to the position of a point on a wave at a given time. It is often measured in terms of angles or fractions of a cycle. The phase of a wave is crucial in understanding interference, a phenomenon where two or more waves overlap.

How Phase Difference Affects Interference:

Constructive Interference:

In-Phase Waves: When waves have the same phase (or a constant phase difference), their amplitudes add up constructively during interference.

Example: In music, when two musical instruments are perfectly tuned to the same frequency and start playing together, their waves interfere constructively, resulting in a louder sound.

Destructive Interference:

Out-of-Phase Waves: When waves have opposite phases (180° phase difference), their amplitudes subtract during interference.

Example: Noise-canceling headphones work by generating sound waves with the same amplitude but opposite phases to incoming noise, leading to destructive interference and reducing overall sound.

Intermediate Cases:

Intermediate Phase Differences: For phase differences between 0° and 180°, interference produces amplitudes between maximum and minimum values.

Example: Radio waves with slightly different phases may interfere constructively or destructively, affecting signal strength and quality.

75. **What are beats ? Mention the essential condition for the formation of beats. Explain the formation of beats by graphical method. How will you determine the unknown frequency of a tuning fork using beats?**

[PYQ NIOS Oct 2022]

Answer:

Beats: Beats are the periodic variation in intensity or loudness produced by the interference of two sound waves with slightly different frequencies. When two waves of nearly equal frequency overlap, they create a pattern of alternating constructive and destructive interference, resulting in a perceived variation in loudness.

Essential Condition for Formation of Beats: The essential condition for the formation of beats is that the frequencies of the two sound waves must be close to each other, but not exactly the same. If the frequencies are too different, no distinct beats will be heard.

Formation of Beats by Graphical Method: Consider two sound waves with frequencies f_1 and f_2, where f_1 is slightly greater than f_2. Represent these frequencies graphically over time. The superposition of these waves results in a pattern where the amplitude varies periodically. The difference in frequency, known as the beat frequency (f_{beat}), is the reciprocal of the time period between successive maxima or minima in the graphical representation.

Determining Unknown Frequency Using Beats: To determine the unknown frequency (f_{unknown}) of a tuning fork using beats:

Known Source: Use a tuning fork with a known frequency (f_{known}).

Create Beats: Strike both the known and unknown tuning forks simultaneously. The interference produces beats.

Count Beats: Count the number of beats heard in a specific time interval.

Calculate Beat Frequency: The beat frequency (f_{beat}) is the difference between the frequencies of the tuning forks: $f_{\text{beat}} = |f_{known} - f_{unknown}|$

Determine Unknown Frequency: Since f_{beat} is known, rearrange the equation to find f_{unknown}: $f_{\text{unknown}} = f_{\text{known}} \pm f_{\text{beat}}$.

Choose the appropriate sign based on the observation of whether the beats are increasing or decreasing.

76. Show that:

(a) Fundamental frequency of open organ pipe is two times the frequency of the fundamental note of a closed pipe of same length.

(b) To produce a fundamental note of same frequency, the length of the open pipe must be two times the length of the closed pipe.[PYQ NIOS Oct 2022]

Answer: (i) The fundamental frequency (f_1) for an open organ pipe is given by the equation: $f_1 = \frac{v}{2l}$

The fundamental frequency (f_1') for an open organ pipe is given by the equation: $f_1' = \frac{v}{4l'}$

Now, let's compare the two frequencies:

$$\frac{f_1}{f_1'} = \frac{\frac{v}{2l}}{\frac{v}{4l'}}$$

Simplifying the expression:

$$\frac{f_1}{f_1'} = \frac{4l'}{2l} = 2$$

This shows that the fundamental frequency of an open organ pipe is two times the frequency of the fundamental note of a closed pipe of the same length.

(ii) Length Ratio for Same Fundamental Frequency:

To produce the same fundamental note, the frequencies must be equal:

$$f_1 = f_1'$$

Substitute the expressions for f_1 and f_1':

$$\frac{v}{2l} = \frac{v}{4l'}$$

Now, solve for the ratio of lengths:

$$\frac{2l}{4l'} = \frac{1}{2}$$

This implies that the length of the open pipe (L) must be two times the length of the closed pipe (L') to produce the same fundamental frequency.

16

Electrostatic potential and capacitance

Short summary

What do we learn

Quick Revision

➢ *Electrostatic potential*

The electrostatic potential at any point in an electric field is equal to the amount of work done per unit positive test charge or in bringing the unit positive test charge from infinite to that point, against the electrostatic force without acceleration.

$$\boxed{\text{Electrostatic potential, } V = \frac{\text{Work done}}{\text{Charge}} = \frac{W}{q}}$$

- Its S.I. unit is volt (V).
- $\boxed{1\ V = 1\ J/C}$
- Its dimensional formula is = $[ML^2T^{-3}A^{-1}]$.
- It is a scalar quantity.

➢ *Electrostatic potential difference*

The electrostatic potential difference between two points in an electric field is defined as the amount of work done in moving a unit positive test charge from one point to the other point against of electrostatic force without any acceleration.

➢ *Electrostatic potential difference*

It is the difference of electrostatic potentials of the two points in the electric field.

Thus, potential difference between points A and B will be:

$$\boxed{V_{AB} = V_B - V_A = \frac{W_{AB}}{q_0}}$$

➢ *Potential energy (U)*

Potential energy of charge q at a point P is the work done by external force in bringing charge q from ∞ to that point. ∞..............................•

$$W_{\infty P} = U_P - U_\infty = U_P - O = U_P$$

- S.I. Unit is joule.
- Other unit is electron volt.

➢ *Electrostatic potential energy difference*

The work done by an external force in moving charge from one point to another for electric field of any arbitrary charge configuration is the electric potential energy difference.

➢ Potential at a point due to a charge

$$V = \frac{1}{4\pi\epsilon_0}.\frac{q}{r} \text{ or } V = k\frac{q}{r}$$

➢ Potential energy at a point due to a charge

$$U = \frac{kqq_0}{r} \text{ Or } U = \frac{1}{4\pi\epsilon_0} \times \frac{qq_0}{r}$$

➢ Potential at a point due to a dipole

In terms of dipole moment: p = $q \times 2l$

$$V = \frac{p\cos\theta}{4\pi\epsilon_0 r^2}$$

- **Potential at an axial point of dipole =** $V = \frac{KP}{r^2 - a^2}$
- **Potential at an axial point of dipole =** $V = 0$

• Potential energy of system of point charges

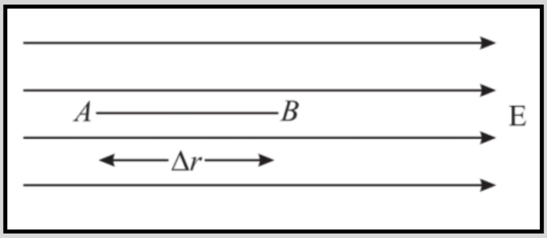
$$U = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_2}{r_{12}} + \frac{q_1q_3}{r_{13}} + \frac{q_2q_3}{r_{23}}\right)$$

➢ Equipotential surfaces

When the potential is same at every point of the surface then these surfaces are called *Equipotential surface.*

1. Work done to move a charge on an Equipotential surface is zero.
2. Electric field is always perpendicular to Equipotential surfaces.
3. Two Equipotential surfaces can never intersect.

➢ Relation between electric field and potential



$$E = -\frac{\Delta V}{\Delta r}$$

NOTE: Negative sign shows that the work is done against the electric field.

At any point, the electric field is equal to negative rate of change of potential with distance, which is called potential gradient at that point in the direction of field.

$$\textbf{Potential gradient} = \frac{-dV}{d}$$

➢ *Classification of substances on the basis of charge*

On the basis of charge conduction, substances are broadly classified as –:

❶ ***Conductors:*** Conductors have free charge carriers through which electric currents can be established on applying an electric field. Metals are good conductors.

❷ **Insulators:** Substances having *no free charge carriers* are called insulators. The common insulators are wood, ebonite, glass, quartz, mica etc.

❸ **Semiconductors:** Substances which have electrical conductivity in between those of conductors and insulators are called semiconductors.

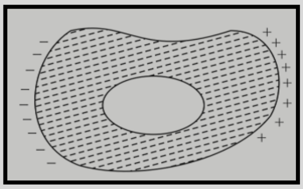
➢ *How does conductors behave in electric field ?*

1. Net electric field inside a conductor is zero.
2. Net charge inside a conductor is zero.
3. Charge always resides on the surface of conductor.
4. Electric field just outside a charged conductor is normal to the surface of conductor at every point.

➢ *Electrostatic shielding*

- Electric field inside a cavity is always zero. Even if the conductor is charged or charges are induced on a neutral conductor by an external field, all charges reside only on the outer surface of the conductor.

Hence, any cavity of any shape and size is always shielded / saved from electric influence, this is called **Electrostatic shielding.**



➢ *Capacitor and Capacitance*

Capacitor is a device that can store amount of charge in a small space.

It is used in many home appliance like fans (condenser is kind of capacitor) , camera , mixer , freeze etc.

Electrical capacitance is a property of the conductor to store charge , denoted by C .

$$\boxed{Q = CV}$$

Where C is the capacitance of the conductor.

$$\Rightarrow \quad \boxed{C = \frac{Q}{V}}$$

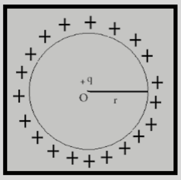
More about Capacitance

∗ Capacitance depends on:
- Shape and size of conductor.
- Nature of medium (dielectric or insulator)

- S.I. Unit of capacitance is **farad.**

$$\boxed{1 \text{ farad} = \frac{1 \text{ coulomb}}{1 \text{ volt}}}$$

Capacitance of a spherical conductor



We know that $C = \frac{Q}{V}$

$$C = \frac{q}{q/4\pi\varepsilon_0 r} = 4\pi\varepsilon_0 r = \frac{r}{9\times10^9}$$

It shows that capacitance of a spherical conductor is directly proportional to its radius.

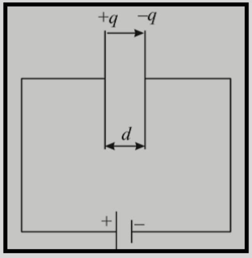
Types of capacitor

There are three types of capacitor -:
1. Parallel plate capacitor
2. Spherical capacitor
3. Cylindrical capacitor

In this chapter we have to read only parallel plate capacitor.

Parallel plate capacitor

A parallel plate capacitor consists of two large plane parallel conducting plates separated by a small distance.



If the plates of a capacitor are separated by a dielectric material other than air or vacuum, the capacitance of a parallel plate capacitor is given by:

$$C = \frac{\varepsilon A}{d} = \frac{k\varepsilon_0 A}{d}$$

Where **ε** is called permittivity of the medium.
So it can be concluded that: $\boxed{C = KC_0}$

Relative permitivity or dielectric constant

$$\frac{F_{vac}}{F_{Med}} = \frac{\epsilon}{\epsilon_0} = \epsilon_r = k = \text{dielectric constant}$$

Dielectric constant (k) can also be expressed as:

$$K = \frac{\text{Capacitance with dielectric between the plates}}{\text{Capacitance with vacuum between the plates}}$$

$$\Rightarrow k = \frac{C_m}{C_0} \Rightarrow C_m = k\,C_0$$

Grouping of capacitors

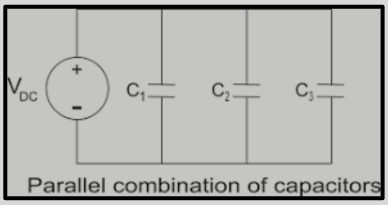
Sometimes a capacitance of a proper value may not be available. In such situations, grouping of capacitors helps us to obtain desired (smaller or larger) value of capacitance with available capacitors.

∗ Two most common capacitor groupings are:

1. Parallel grouping
2. Series grouping

Parallel grouping

Capacitors are said to be connected inparallel when the first and second plate getting joint together at a point.



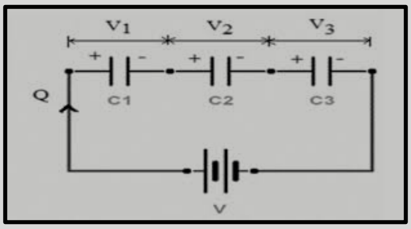
Parallel combination of capacitors

- The potential difference across thearrangement will remain same.
- The total charge is the sum ofindividual charges across each capacitor.
- The total capacitance is sum ofindividual capacitance.

$$C = C_1 + C_2 + C_3 + \ldots.. + C_n$$

Series grouping

Capacitors are said to be connected inseries when the second plate of the capacitor is connected to the first plate of the next capacitor and so on.



- The charge across the arrangementwill remain same.
- The potential drop is the sum of individual potential drop across eachcapacitance.
- The inverse of total capacitance isthe sum of inverse of each capacitance.

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots. + \frac{1}{C_n}$$

Energy stored in capacitor

$$U = \frac{1}{2} CV^2$$

Dielectric

Dielectrics are non – conducting substances having negligible numberof charge carriers.

Example: Porcelain, Mica, Glass etc.

Question – Answers

① MCQs

1. What is electrostatic potential at a point in an electric field?

(A) The electric field strength
(B) The electric potential energy at that point
(C) The charge at that point
(D) The work done in bringing a unit positive charge from infinity to that point

Answer: **(D) The work done in bringing a unit positive charge from infinity to that point**

2. What is the SI unit of electric potential?

(A) Volt (B) Joule (C) Coulomb (D) Ohm

Answer: **(A) Volt**

3. The electric potential is a scalar quantity. What does this mean?

(A) It has both magnitude and direction.
(B) It has only magnitude.
(C) It has only direction.
(D) It has neither magnitude nor direction

Answer: **(B) It has only magnitude**

4. In a uniform electric field, the electric potential:

(A) Decreases with distance.
(B) Increases with distance.
(C) Remains constant.
(D) Becomes zero.

Answer: **(B) Increases with distance**

5. What is the relationship between electric potential (V), electric field (E), and distance (d) in a uniform electric field?

(A) $V = E/d$ (B) $V = Ed$ (C) $V = E + d$ (D) $V = E \times d$

Answer: **(B) V = Ed**

6. **What is the potential difference between two points in an electric field if the work done in moving a charge of 2 C between them is 8 J?**
   (A) 2 V (B) 4 V (C) 6 V (D) 8 V

Answer: **(B) 4 V**

7. **The electric potential energy of a system of charges is zero when:**
   (A) The charges are close to each other.
   (B) The charges are at an infinite distance from each other.
   (C) The charges have the same sign.
   (D) The charges have opposite signs.

Answer: **(B) The charges are at an infinite distance from each other**

8. **In a parallel plate capacitor, the capacitance depends on:**
   (A) The area of the plates and the separation between them.
   (B) Only the area of the plates.
   (C) Only the separation between the plates.
   (D) The charge on the plates.

Answer: **(A) The area of the plates and the separation between them.**

9. **When the distance between the plates of a capacitor is doubled, the capacitance:**
   (A) Doubles (B) Halves (C) Quadruples (D) Remains same

Answer: **(B) Halves**

10. **The dielectric material is inserted between the plates of a capacitor. What effect does it have on the capacitance?**
    (A) Increases (B) Decreases (C) Remains same (D) Becomes zero

Answer: **(A) Increases**

11. **What is the unit of capacitance (C)?**
    (A) Volt (B) Ampere (C) Farad (D) Coulomb

Answer: **(C) Farad**

12. **When a capacitor is connected to a battery, what is responsible for the flow of current?**
    - (A) Electric field between the plates
    - (B) Change in potential energy
    - (C) Potential difference across the plates
    - (D) Dielectric constant

Answer: **(C) Potential difference across the plates**

13. **In a series combination of capacitors, the total capacitance is:**
    - (A) The sum of the individual capacitances
    - (B) The product of the individual capacitances
    - (C) Inversely proportional to the individual capacitances
    - (D) Directly proportional to the individual capacitances

Answer: **(C) Inversely proportional to the individual capacitances**

14. **What happens to the capacitance of a parallel plate capacitor if the area of the plates is increased?**
    (A) Increases (B) Decreases (C) Remains same (D) Becomes zero

Answer: **(A) Increases**

15. **The potential due to appoint charge Q, at a point distance r from it, is:**
    [PYQ NIOS April 2022]
    - (A) Inversely proportional to r
    - (B) Inversely proportional to r^2
    - (C) Directly proportional to r
    - (D) Directly proportional to r^2

Answer: **(A) Inversely proportional to r**

16. **The process in which a region is made free from any electric field is known as:**
    - (A) Electrostatic forcing
    - (B) Electrostatic binding
    - (C) Electrostatic shielding

(D) None of the options

Answer: **(C) Electrostatic shielding**

17. **The formula for electrostatic potential is:**
    - (A) Electrostatic potential = Work done × charge
    - (B) Electrostatic potential = Work done/charge
    - (C) Electrostatic potential = Work done + charge
    - (D) Electrostatic potential = Work done - charge

Answer: **(B) Electrostatic potential = Work done/charge**

18. **The work done in moving a unit positive test charge over a closed path in an electric field is:**

(A) Always 1 (B) Infinite (C) Zero (D) Negative

Answer: **(C) Zero**

19. **The capacity of the parallel plate capacitor increases when:**
    - (A) area of the plate is decreased
    - (B) area of the plate is increased
    - (C) distance between the plates increases
    - (D) None of the option

Answer: **(D) area of the plate is increased**

20. **Two conducting spheres of radii r_1 and r_2 ($r_1 > r_2$) are at the same electric potential. The ratio of charges on them is: [PYQ NIOS Oct 2022]**

(A) $\frac{r_1}{r_2}$ (B) $\frac{r_2}{r_1}$ (C) $\frac{r_1^2}{r_2^2}$ (D) $\frac{r_2^2}{r_1^2}$

Answer: **(B) $\frac{r_2}{r_1}$**

② Complete the sentence using an appropriate word:

21. **Separation, area, charge, farad, voltage**

(a) The electric potential difference is also known as **………….**

(b) Capacitance is a measure of a capacitor's ability to store …………….

(c) The unit of capacitance is the ……………

(d) The capacitance of a parallel plate capacitor depends on the …………… of the plates.

(e) The capacitance of a parallel plate capacitor is inversely proportional to the …………….. between the plates.

Answer: **(a) voltage, (b) Charge, (c) Farad, (d) Area, (e) Separation**

③ fill in the blanks

22.

(a) The electric potential is a ………… quantity.

(b) The potential difference between two points is the ………… work done in moving a charge from one point to the other.

(c) The potential energy stored in a capacitor is given by the formula …………….

(d) The energy stored in a capacitor is directly proportional to the ………… on the plates and the square of the potential difference.

(e) A capacitor connected to a battery will initially behave like a …………. circuit.

(f) The ………… of a point in an electric field is defined as the amount of work done in bringing a unit positive charge from infinity to that point.

(g) The electric potential is a …………… quantity.

(h) The unit of electric potential is ………….

(i) The electric potential at a point is the electric potential energy per ………. charge at that point.

Answer: **(a) Scalar, (b) Negative, (c) $U = 1/2\ CV^2$ (d) Charge, (e) Closed,**
(f) Electric Potential (g) Scalar, (h) Volt, (i) Unit

④ Match the following:

23. Match column I statement with the right statement of column II.

Column I	Column II
1. Dielectric constant	**A.** Work done to assemble a configuration of charges
2. Dielectric polarization	**B.** Alignment of dipoles in a dielectric material
3. Equipotential surfaces	**C.** Increase capacitance
4. Electric potential	**D.** A surface where the electric potential is the same at every point
5. Electric potential energy	**E.** Electric potential energy per unit charge

Answer: 1 – C, 2 – A, 3 – D, 4 – E, 5 - A

24. Match the statement of column I with suitable statement given in column II.

Coulmn I	Column II
1. Unit of capacitance	A. Volt
2. Unit of potential	B. $M^{1}L^{2}T^{-3}I^{-1}$
3. Unit of potential energy	C. Farad
4. Dimensional formula of potential	D. $M^{-1}L^{-2}T^{4}I^{2}$
5. Dimensional formula of capacitance	E. Joule

Answer: 1 – C, 2 – A, 3 – E, 4 – B, 5 – E

⑤ Very short type question answer [2 marks of each]

25. How is electric potential different from electric potential energy?

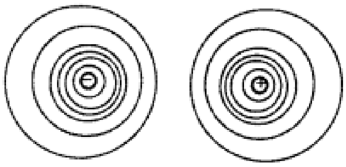
Answer: Electric potential is the electric potential energy per unit charge at a point, while electric potential energy is the work done to assemble a configuration of charges.

$$\text{Electric potential (V)} = \frac{\text{Potential energy}}{\text{charge}} = \frac{V}{q_0}$$

$$\text{Potential energy (U)} = \frac{kq}{r}$$

26. Two charges 2μC and – 2μC are placed at points A and B 5 cm apart. Depict an equipotential surface of the system.

Answer:



Equipotential surfaces of the system

27. Do free electrons travel to regions of higher potential or lower potential?

Answer: The free electrons experience an electrostatic force in the opposite direction of the electric field due to their negative charge. Since the electric field always moves from higher potential to lower potential, the electrostatic force and the direction of travel of the electrons is from the region of lower potential to the region of higher potential.

28. For any charge configuration, equipotential surface through a point is normal to the electric field." Justify.

Answer: Work done in moving a charge over an equipotential surface is zero, hence a point on it will be normal to the electric field.

$W = FS \cos \theta$

$\therefore \cos \theta = 0$ or $\theta = 90°$

29. Can two equipotential surfaces intersect each other? Give reasons.

Answer: No, if they intersect, there will be two different directions of electric field at that point which is not correct. If they intersect, then at the same point of intersection, there will be two values of potential. This is not possible and hence two equipotential surfaces cannot intersect.

30. Why does the electric field inside a dielectric decrease when it is placed in an external electric field?

Answer: The electric field that is present inside a dielectric decreases when it is placed in an external electric field because of polarisation as it creates an internal electric field which is opposite to the external electric field inside a dielectric due to which the net electric field gets reduced.

31. Show mathematically that the potential at a point on the equatorial line of an electric dipole is Zero?

Answer: Electric potential at point on the equatorial line of an electric dipole can be expressed mathematically as:

$$V = V_{PA} + V_{PB}$$

$$\Rightarrow V = \frac{K(-q)}{r} + \frac{K(+q)}{r}$$

$$\Rightarrow V = 0$$

32. (i) Is it possible for two equipotential surfaces to intersect? Give reasons.

(ii) At positions A (0, 0, -a) and B (0, 0, +a), respectively, are two charges, -q and +q. In transferring a test charge from location P (7, 0, 0) to point Q (-3, 0, 0), how much work is involved?

Answer: **(i)** This is incorrect because if they connect, the electric field there would be pointing in two distinct directions. If they do, there will be two potential values present at the junction. As a result, two equipotential surfaces cannot intersect because this is not conceivable.

(ii) Since V = 0 at every point on the dipole's equatorial line, which includes points P and Q, there will be no work done. Additionally, since any force of a charge is perpendicular to the equatorial line, no work is done.

33. Describe schematically the equipotential surfaces corresponding to

- **(a) A constant electric field in the z-direction,**
- **(b) A single positive charge at the origin, and**

Answer: **(a)** Equidistant planes which are parallel to the x-y plane are the equipotential surfaces.

(b) Concentric spheres centred at the origin are equipotential surfaces.

34. Two charges -q and + q are located at points A (0, 0, – a) and B (0, 0, +a) respectively. How much work is done in moving a test charge from point P (7, 0, 0) to Q (-3,0,0)?

Answer: Since both the points P and Q are on the equatorial line of the dipole and V = 0 at every point on it, work done will be zero. Also the force on any charge is perpendicular to the equatorial line, so work done is zero.

35. Give one difference between dielectric and a conductor.

Answer:

Dielectric	Conductor
Dielectrics are the insulating materials which transmit electric effects without conducting.	Conductors are the substances which can be used to carry or conduct electric charge from one place to the other.

36. Is the electric field inside a cavity (with no charge) zero, even if the shell is not spherical, but any irregular shape? Explain.

Answer: Yes, the electric field intensity which is inside a cavity is zero, even if the shell is not spherical and has any irregular shape. Now, take a closed loop such that a part of it is inside the cavity along a field line while the rest is inside the conductor. Net work done by the field in carrying a test charge over a closed loop will be zero due to the field inside the conductor being zero. Therefore, the electric field is zero, whatever the shape.

37. Do free electrons travel to regions of higher potential or lower potential?

Answer: The free electrons experience an electrostatic force in the opposite direction of the electric field due to their negative charge. Since the electric field always moves from higher potential to lower potential, the electrostatic force and the direction of travel of the electrons is from the region of lower potential to the region of higher potential.

38. A parallel plate capacitor is charged to a potential difference V between its plates. Explain how will the energy stored in capacitor change

when the separation between its plates is doubled keeping the value of V same. **[PYQ NIOS Jan 2021]**

Answer: energy of capacitor, U = $\frac{1}{2}\frac{Q^2}{C}$

Since Q remains the same but the capacitance decreses,

$$U' = \frac{1}{2}\frac{Q^2}{\frac{C}{2}}$$

$$\Rightarrow \quad \frac{U}{U'} = \frac{1}{2}$$

$$\Rightarrow \quad U' = 2U$$

Hence the energy stored in the capacitor gets doubled when the distance between plates is doubled.

39. **A capacitor has some dielectric between its plates, and the capacitor is connected to a DC source. The battery is now disconnected, and then the dielectric is removed. State whether the capacitance, the energy stored in it, the electric field, the charge stored, and the voltage will increase, decrease or remain constant.**

Answer: When a capacitor is connected to a DC source, it becomes charged.

When the battery is disconnected, no more charge can flow into the capacitor. Removing the dielectric material from the capacitor will cause its capacitance to decrease.

Energy stored will rise $\left(u = \frac{q^2}{2C}\right)$

Potential will also rise $\left(\mathrm{V} = \frac{\mathrm{q}}{\mathrm{C}}\right)$

Electric field will rise $\left(\mathrm{E} = \frac{\mathrm{V}}{\mathrm{D}}\right)$

40. **The four capacitors C_1, C_2, C_3 and C_4 each of 25 μF, are connected in a circuit as shown in the figure. The DC voltmeter (V) reads 200 V. Find the charge on each capacitor.** **[PYQ NIOS Oct 2022]**

Answer: The two capacitors on the left side are in parallel and potential across each equal to V.

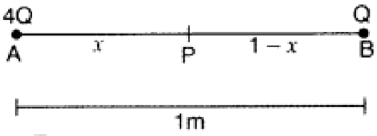
Similarly the capacitors on right side are in parallel and potential across each equal to V.

Therefore charge on each plate of capacitor is

$$Q = \pm CV = \pm 25 \times 10^{-6} \times 200 = \pm 5 \times 10^{-3}\ J$$

41. **Two point charges 4Q, Q are separated by lm in air. At what point on the line joining the charges is the electric field intensity zero?**
Also calculate the electrostatic potential energy of the system of charges, taking the value of charge, $Q = 2 \times 10^{-7}$C

Answer: (i) Given: $r = 1$m, $q_1 = 4Q$, $q_2 = Q$



$$E_{PA} = E_{PB}$$

$$\frac{K(4Q)}{x^2} = \frac{KQ}{(1-x)^2} \qquad \Rightarrow \frac{4}{x^2} = \frac{1}{(1-x)^2}$$

$$\Rightarrow \frac{2}{x} = \frac{1}{1-x} \qquad \Rightarrow 2 - 2x = x$$

$$\Rightarrow 3x = 2 \qquad \therefore x = \frac{2}{3}\,\mathbf{m}$$

(ii) Electrostatic potential energy of the system is:

$$U = K\frac{q_1 q_2}{r} = \frac{9 \times 10^9 \times 4Q \times Q}{1}$$
$$= 36 \times 10^9 \times (2 \times 10^{-7})^2 = \mathbf{1.44 \times 10^{-3}\ J}$$

42. **(i) Can two equipotential surfaces intersect each other? Give reasons.**
(ii) Two charges -q and + q are located at points A (0, 0, – a) and B (0, 0, +a) respectively. How much work is done in moving a test charge from point P (7, 0, 0) to Q (-3,0,0)?

Answer:

(i) No, if they intersect, there will be two different directions of electric field at that point which is not correct. If they intersect, then at the same point of intersection, there will be two values of potential. This is not possible and hence two equipotential surfaces cannot intersect.

(ii) Since both the points P and Q are on the equatorial line of the dipole and V = 0 at every point on it, work done will be zero. Also the force on any charge is perpendicular to the equatorial line, so work done is zero.

43. **Assuming the earth to be a spherical conductor of radius 6400 km, calculate its capacitance.**

Answer: capacitance of earth C = $4\pi\epsilon_0 r$

Here, $4\pi\epsilon_0 = \frac{1}{9 \times 10^9}$r = 6400 km = 6.4×10^6 mC

$= \frac{6.4 \times 10^6}{9 \times 10^9} = 0.71 \times 10^{-3}$ F = 711 μF.

44. Imagine there are two charges, 2C and 2C, that are placed 6 cm apart from points A and B. Find the following.

(a) The equipotential surface of the system

(b) The electric field direction that exists at every point on the given surface

Answer: **(a)** The plane where the total potential is zero everywhere is referred to as an equipotential surface. This plane is typical for line AB. Because the magnitude of the charges is the same throughout line AB, the plane is situated at its midpoint.

(b) Every point on this surface has an electric field that is normal to the plane and points in the direction of AB.

45. Given that there is a 0.5cm gap between the plates of a 2F parallel plate capacitor, what is the area of the plates? (You'll see from your response why standard capacitors have a range of F or less. However, due to the extremely thin spacing between the electrolytic capacitors, electrolytic capacitors do have a significantly higher capacitance of 0.1F.)

Answer: The capacitance of a parallel capacitor can be written as V = 2F.

The gap between the two plates will be written as d = 0.5cm = 0.5×10^{-2}m.

The Capacitance of a parallel plate capacitor can be represented by

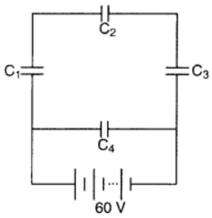
$A = 2 \times 0.5 \times 10^{-2} \times 8.85 \times 10^{-12}$

A = 1130 km^2

Therefore, the plate's area is too big. The capacitance of the F range is taken to avoid this situation.

⑥ short type question answer [3 marks of each]

46. **A network of four capacitors, each of capacitance 30 pF, is connected across a battery of 60 V as shown in the figure. Find the net capacitance and the energy stored in each capacitor.**



Answer:

$$\frac{1}{C'} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

...[$\because$ C_1, C_2 and C_3 are in series

or $$\frac{1}{C'} = \frac{1}{30} + \frac{1}{30} + \frac{1}{30} = \frac{3}{30} = \frac{1}{10}$$

$\therefore$ $C' = 10\ \mu F$

C_4 and C' are in parallel

$\therefore$ $C_{net} = C' + C_4 = 10 + 30 = \mathbf{40\ \mu F}$

Energy stored in C_1, C_2 and C_3 = $\frac{1}{2}C'V^2$

$$= \frac{1}{2} \times 10 \times 10^{-6} \times 3600\ J = 18 \times 10^{-3}\ J$$

Energy stored in each of the capacitor C_1, C_2 and C_3 = $\mathbf{6 \times 10^{-3}\ J}$

$\therefore$ Energy stored in capacitor C_4

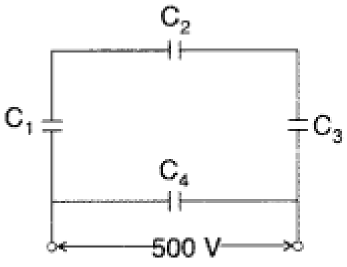
$= 1/2 \times (30 \times 10^{-6} \times 3600)\ J$

$= 54000 \times 10^{-6} = \mathbf{5.4 \times 10^{-2}\ J}$

47. **A network of four capacitors each of 12µF capacitance is connected to a 500 V supply as shown in the figure.**

Determine (a) equivalent capacitance of the network and

(b) charge on each capacitor.



Answer:

(a) Equivalent capacitance of the network,

$$C_{123} = \frac{12\mu F}{3} = 4\ \mu F(\because \text{ being in series})\ldots(i)$$

$$C_{eq} = C_{123} + C_4 = (4 + 12)\ \mu F = \mathbf{16\ \mu F}$$

...[From (*i*)

(*b*) (*i*) $Q = CV, \qquad Q_1 = C_4V$

$\therefore\ Q_1 = 500 \times 12 \times 10^{-6}$

$= 6000 \times 10^{-6} = 6 \times 10^{-3}$ C

$\therefore$ Charge on capacitor,

$C_4 = \mathbf{6 \times 10^{-3}\ C}$

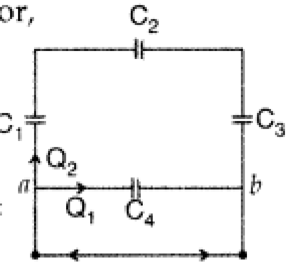
(*ii*) $Q_2 = C_{123}\ V$

$= (4 \times 10^{-6}) \times 500$

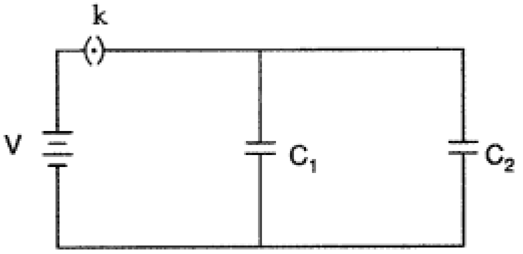
$= 2 \times 10^{-3}$ C

$\therefore$ Charge on each of the capacitors C_1, C_2 and C_3

$= \mathbf{2 \times 10^{-3}}$ C



48. **Two parallel plate capacitors of capacitances C_1 and C_2 such that $C_1 = 3C_2$ are connected across a battery of V volts as shown in the figure. Initially the key (k) is kept dosed to fully charge the capacitors. The key is now thrown open and a dielectric slab of dielectric constant 'K' is inserted in the two capacitors to completely fill the gap between the plates,**



Find the ratio of

(i) the net capacitance and

(ii) the energies stored in the combination, before and after the introduction of the dielectric slab.

Answer:

(i) Net capacitance before filling the gap with dielectric slab

$$C_{\text{initial}} = C_1 + C_2 = 3C_2 + C_2 = 4C_2$$

Net capacitance after filling the gap with dielectric slab of dielectric constant 'K'

$$C_{\text{final}} = KC_1 + KC_2 = 3KC_2 + KC_2 = 4KC_2$$

∴ Ratio of net capacitance,

$$\frac{C_{\text{initial}}}{C_{\text{final}}} = \frac{4C_2}{4KC_2} = \frac{\mathbf{1}}{\mathbf{K}}$$

(ii) Energy stored in the combination before introduction of dielectric slab,

$$U_{\text{initial}} = \frac{Q^2}{3C_2}$$

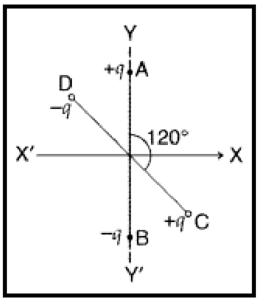
Energy stored in the combination after introduction of dielectric slab,

$$U_{\text{final}} = \frac{Q^2}{3KC_2}$$

∴ Ratio of energy stored

$$\frac{U_{\text{initial}}}{U_{\text{final}}} = \frac{Q^2}{3C_2} \Big/ \frac{Q^2}{3KC_2} = \frac{K}{1} = \mathbf{K}$$

49. **Two small identical electrical dipoles AB and CD, each of dipole moment 'p' are kept at an angle of 120° as shown in the figure. What X' is the resultant dipole moment of this combination? If this system is subjected to electric field (E→) directed along + X direction, what will be the magnitude and direction of the torque acting on this?**



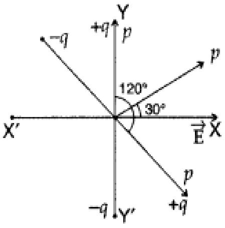
Answer: Resultant dipole moment of both dipoles is

$$= \sqrt{p^2 + p^2 + 2p^2 \cos\theta}$$

$$= \sqrt{2p^2 + 2p^2 \cos 120^\circ}$$

$$= \sqrt{2p^2 + 2p^2\left(-\frac{1}{2}\right)}$$

$$= \sqrt{p^2} = p$$



Resultant dipole moment (p) makes an angle of 60° with each dipole and 30° with x - axis as shown in the figure.

$$\text{Now } \tau = pE \sin 30^\circ = pE\left(\frac{1}{2}\right) \quad \Rightarrow \boxed{\tau = \frac{pE}{2}}$$

50. Three capacitors each of capacitance 9 μF are connected in series.

(a) What is the total capacitance of the combination?

(b) What is the potential difference across each capacitor if the combination is connected to a 120V supply?

Answer: (a) Capacitance of each of the three capacitors, C = 9 μF

Equivalent capacitance of the combination of the capacitors = C′, which is given by the relation,

$$\Rightarrow \quad \frac{1}{C'} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C}$$

$$\Rightarrow \quad \frac{1}{C'} = \frac{1}{9} + \frac{1}{9} + \frac{1}{9} = \frac{3}{9}$$

$$\Rightarrow \quad C' = 3\ \mu F$$

(b) Supply voltage is given as, V = 120 V

Potential difference $\vec{V}$ across each capacitor is equal to one-third of the supply voltage.

$$V' = \frac{V}{3} = \frac{120}{3} = 40\ V$$

51. Justify that the electrostatic potential is constant throughout the volume of a charged conductor and has the same value on its surface as inside it.

Answer: since electric field inside the conductor is zero and has no tangential component on the surface, no work is done in moving a small test charge within the conductor or on its surface.

This means that, there is no potential difference between any two points inside or on the surface of the conductor. Hence the potential is constant throughout the volume of the conductor and has the same value on its surface.

52. A constant electric field holds an electric dipole in place.

(i) Demonstrate that there is no net force operating on it.

(ii) The dipole is parallel to the field in alignment.

Find the work that was done to rotate it via a 180° angle.

Answer: (i) Force resulting from charge -q is -qE acting on point A

Point B is exposed to a force from charge +q is + qE.

The net force acting on = -qE + qE = 0

Hence, the net force acting on an electric dipole held in a uniform electric field is zero.

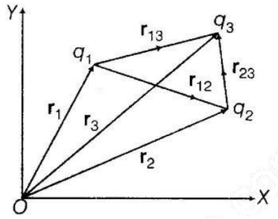
(ii) $W = -pE (\cos \theta_2 - \cos \theta_1)$

$\Rightarrow W = -pE (\cos 180° - \cos 0°)$

$\Rightarrow W = -pE [-1 - (1)] = +2pE$

53. Find out the expression for the potential energy of a system of three charges q_1, q_2 and g_3 located at q , r_2 and r_3 with respect to the common origin O.

Answer: Let three point charges q_1, q_2 and q_3 have position vectors $\mathbf{r}_1$, $\mathbf{r}_2$ and $\mathbf{r}_3$, respectively.



Potential energy of the charges q_1 and q_2,

$$U_{12} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{|\mathbf{r}_{12}|} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{|\mathbf{r}_2 - \mathbf{r}_1|}$$

Similarly, $U_{23} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_2 q_3}{|\mathbf{r}_3 - \mathbf{r}_2|}$

$$U_{31} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_3}{|\mathbf{r}_3 - \mathbf{r}_1|} \qquad \textbf{(1)}$$

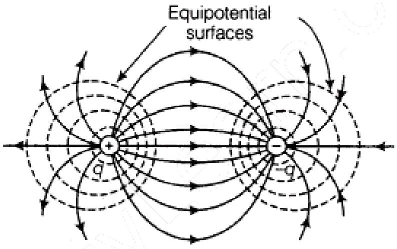
$\therefore$ Net potential energy of the system,

$$U = U_{12} + U_{23} + U_{31}$$

$$U = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1 q_2}{|\mathbf{r}_2 - \mathbf{r}_1|} + \frac{q_2 q_3}{|\mathbf{r}_3 - \mathbf{r}_2|} + \frac{q_1 q_3}{|\mathbf{r}_3 - \mathbf{r}_1|}\right] \qquad \textbf{(1)}$$

54. (i)Write two characteristics of equipotential surfaces.
(ii) Draw the equipotential surfaces due to an electric dipole.

Answer: (i) Two equipotential surfaces do not intersect each other as normals at intersecting points on two surfaces will give two directions of electric field which is impossible.
(ii) Closely spaced equipotential surfaces represent strong electric field and vice - versa.



Equipotential surfaces due to an electric dipole

55. A wire AB is carrying a steady current of 12 A and is lying on the table. Another wire CD carrying 5 A is held directly above AB at a height of 1mm. Find the mass per unit length of the wire CD, so that it remains suspended at its position when left free. Give the direction of the current flowing in CD with respect to that in [Take the value of g =10 ms-2]

Answer: Force per unit length between the current carrying wires is given as

$$F = \frac{\mu_0}{4\pi} \cdot \frac{2I_1I_2}{r}$$

where, I_1 = current in wire, $AB = 12$ A and I_2 = current in wire, $CD = 5$ A and r = distance between wires = 1mm $= 1\times10^{-3}$ m

$$\therefore \quad \frac{\mu_0}{4\pi} \frac{2I_1I_2}{r} = mg$$

Here, m is mass per unit length.

$$\Rightarrow \quad 10^{-7} \times \frac{2\times12\times5}{1\times10^{-3}} = m\times10$$

$$\Rightarrow \quad m = 10^{-7} \times \frac{2\times12\times5}{1\times10^{-3}} \times \frac{1}{10}$$

$$= 1.2\times10^{-3} \text{ kg/m}$$

⑦ Long type question answer [4 marks of each]

56. **Two point charges q and –q are located at points (0,0, -a) and (0,0,a) respectively.**

(i) Find the electrostatic potential at (0,0,z) and (x,y,0).

(ii) How much work is done in moving a small test charge from the point (5,0,0) to (-7,0,0) along the x – axis?

(iii) How would your answer change if the path of the test charge between the same points is not along the x – axis but along any other random path?

(iv) If the above point charges are now placed in the same positions in a uniform external electric field $\vec{E}$, what would be the potential energy of the charge system in its orientation of unstable equilibrium? Justify your answer in each case.

Answer: **(i)** Zero at both the points

Charge − q is located at (0, 0, − a) and charge + q is located at (0, 0, a). Hence, they form a dipole. Point (0, 0, z) is on the axis of this dipole and point (x, y, 0) is normal to the axis of the dipole.

Hence, electrostatic potential at point (x, y, 0) is zero. Electrostatic potential at point (0, 0, z) is given by,

$$\Rightarrow \quad V = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{z-a}\right) + \frac{1}{4\pi\epsilon_0}\left(-\frac{q}{z+a}\right)$$

$$\Rightarrow \quad V = \frac{q(z+a-z+a)}{4\pi\epsilon_0(z^2-a^2)} = \frac{2qa}{4\pi\epsilon_0(z^2-a^2)} = \frac{p}{4\pi\epsilon_0(z^2-a^2)}$$

(ii) Work done is Zero.

(iii) The answer does not change if the path of the test is not along the x-axis. As work done does not depend on the path .It depends on the final and initial position. Work done will continue to zero along every path.

(iv) Dipole moment of charge system is as p = | q | × 2 a, when dipole is placed external uniform field E is in unstable equilibrium then $\theta = 180^\circ$

Potential energy (P.E) = $-\,p\,E\cos\theta = -\,q \times 2\,a \times E\cos 180^\circ = q \times 2\,a\,E$

57. **Three capacitors of capacitances 2 pF, 3 pF and 4 pF are connected parallel to one another. As per the data, determine,**

(i) The total capacitance of the combination.

(ii) Establish the amount of charge on each capacitor, considering the combination is connected to a 100V supply.

Answer: **(i)** As per the given data, C_1 = 2pF, C_2 = 3pF, C_3 = 4pF.

Equivalent capacitance for the parallel combination is given as: $C_{eq} = C_1 + C_2 + C_3$

$\Rightarrow C_{eq} = 2 + 3 + 4 = 9\text{pF}$

(ii) Supply voltage can be shown by, V = 100V

The three capacitors are known to have the same voltage, V = 100v

As per the formula, q = VC

For capacitance → C = 2pF, q = 100 x 2 = 200pC = 2×10^{-10}C

For capacitance → C = 3pF, q = 100 x 3 = 300pC = 3×10^{-10}C

For capacitance → C = 4Pf, q = 100 x 4 = 400pC = 4×10^{-10} C

58. **(a) Define dielectric constant in terms of the capacitance of a capacitor? On what factor does the capacitance of a parallel plate capacitor with dielectric depend?**

(b) Find the ratio of the potential differences that must be applied across the (i) parallel (ii) Series combination of two identical capacitors so that the energy stored in the two cases becomes the same.

Answer: **(a)** Dielectric constant is defined as the ratio of capacitance of a capacitor when the dielectric is filled in between the plates to the capacitance of a capacitor when there is vacuum in between the plates in terms of dielectric constant

$$k = \frac{C_m \text{ Capacitance of a capcitor when dielectric is in between the plates}}{C_o \text{ Capacitance of a capcitor with vaccuum in between the plates.}}$$

Capacitance of a parallel plate capacitor with dielectric depends on the following factors $C_m = \frac{k\epsilon_0 A}{d}$

- Area of the plates
- Distance between the plates
- Dielectric constant of the dielectric between the plates

(b) Let the capacitance of each capacitor be C

$C_p = C + C = 2C$ (in parallel)

$C_S = \frac{C \times C}{C+C} = \frac{C}{2}$ (in series)

Let V_p and V_S be the values of potential difference

This $Up = \frac{1}{2}CpVp^2 = \frac{1}{2} \times 2C \times Vp^2 = CVp^2$

$$Us = \frac{1}{2}CsVs^2 = \frac{1}{2} \times \frac{C}{2} \times Vs^2 = \frac{CVs^2}{4}$$

But $U_p = U_S$ (given)

$$CVp^2 = \frac{CVs^2}{4}$$

$$\frac{Vp^2}{Vs^2} = 1/4$$

$\Rightarrow V_p : V_s = 1 : 2$

59. **Show that the force on each plate of a parallel plate capacitor has a magnitude equal to $\frac{1}{2}$ QE, where Q is the charge on the capacitor, and E is the magnitude of electric field between the plates. Explain the origin of the factor $\frac{1}{2}$.**

Answer: Let F be the force applied to separate the plates of a parallel plate capacitor by a distance of Δx.

Hence, work done by the force to do so = FΔx

As a result, the potential energy of the capacitor increases by an amount given as uAΔx.

Where, u = Energy density

A = Area of each plate

d = Distance between the plates

V = Potential difference across the plates

The work done will be equal to the increase in the potential energy i.e.,

$$F\Delta x = uA\Delta x$$

$$F = uA = \left(\frac{1}{2}\epsilon_0 E^2\right)A$$

Electric intensity is given by, E = $\frac{V}{d}$

$$\therefore F = \frac{1}{2}\epsilon_0\left(\frac{V}{d}\right)EA = \frac{1}{2}\left(\epsilon_0 A\frac{V}{d}\right)E$$

However, capacitance, C = $\frac{\epsilon_0 A}{d}$

$$\therefore F = \frac{1}{2}(CV)E$$

Charge on the capacitor is given by, Q = CV

$$\therefore F = \frac{1}{2}QE$$

The physical origin of the factor, $\frac{1}{2}$, in the force formula lies in the fact that just outside the conductor, field is E and inside it is zero. Hence, it is the average value, $\frac{E}{2}$, of the field that contributes to the force.

⑧ Very Long type question answer [5 marks of each]

60. Explain the concept of electric potential and its relationship with electric field. Derive the expression for the electric potential due to a point charge.

Answer:

Electric Potential: Electric potential is the amount of work done in moving a unit positive charge from one point to another in an electric field. It is a scalar quantity and is measured in volts (V).

Relationship with Electric Field:

The electric field (E) at a point is defined as the force (F) experienced by a positive test charge (q_0) placed at that point, divided by the magnitude of the test charge.

Mathematically, **E =** $\mathbf{\frac{F}{q_0}}$

The electric potential (V) at a point is related to the electric field by the equation: **E = $-\frac{\mathbf{dV}}{\mathbf{dr}}$**

This implies that the electric field is the negative gradient of the electric potential.

Derivation of Electric Potential due to a Point Charge:

Consider a point charge Q at a distance r from a point in space. To find the electric potential (V) at a point due to this charge, we start with the definition of electric potential energy (U).

The electric potential energy (U) is the work done (W) in bringing a test charge (q_0) from infinity to a distance r from the charge. Mathematically, U = W

$$U = \int_{\infty}^{r} F\, dr$$

Now, using Coulomb's Law $\left(F = \frac{kQq_0}{r^2}\right)$ we can express F in terms of r:

$$U = \int_{\infty}^{r} \frac{kQq_0}{r^2}\, dr$$

Integrating with respect to r, we get:

$$U = -\left[\frac{kQq_0}{r^2}\right]_{\infty}^{r}$$

$$\Rightarrow \quad U = -\frac{kQq_0}{r}$$

Now, we know that U is also equal to the electric potential energy gained by the test charge, which is q_0V. Therefore:

$$q_0 = -\frac{kQq_0}{r}$$

$$\Rightarrow V = \frac{kQ}{r}$$

This is the expression for the electric potential (V) at a distance (r) from a point charge Q.

61. Answer carefully:

1. Two large conducting spheres carrying charges Q_1 and Q_2 are brought close to each other. Is the magnitude of electrostatic force between them exactly given by $Q_1 Q_2 / 4n^{e0} r^2$, where r is the distance between their centres?

2. If Coulomb's law involved $1/r^3$ dependence (instead of $1/r^2$), would Gauss's law be still true?

3. A small test charge is released at rest at a point in an electrostatic field configuration. Will it travel along the field line passing through that point?

4. What is the work done by the field of a nucleus in a complete circular orbit of the electron? What if the orbit is elliptical?

5. We know that electric field is discontinuous across the surface of a charged conductor. Is electric potential also discontinuous there?

6. What meaning would you give to the capacitance of a single conductor?

7. Guess a possible reason why water has a much greater dielectric constant (= 80) than say, mica (= 6).

Answer:

1. The force between two conducting spheres is not exactly given by the expression **$Q_2 / 4n^{e0} r^2$**, because there is a non-uniform charge distribution on the spheres.

2. Gauss's law will not be true, if Coulomb's law involved $1/r^3$ dependence, instead of $1/r^2$, on r.

3. Yes, If a small test charge is released at rest at a point in an electrostatic field configuration, then it will travel along the field lines passing through the point,

only if the field lines are straight. This is because the field lines give the direction of acceleration and not of velocity.

4. Whenever the electron completes an orbit, either circular or elliptical, the work done by the field of a nucleus is zero.

5. No Electric field is discontinuous across the surface of a charged conductor. However, electric potential is continuous.

6. The capacitance of a single conductor is considered as a parallel plate capacitor with one of its two plates at infinity.

7. Water has an unsymmetrical space as compared to mica. Since it has a permanent dipole moment, it has a greater dielectric constant than mica.

62. Investigate the concept of potential due to a charged conducting sphere. Derive the expression for the potential inside and outside the sphere. Discuss the behavior of potential as one moves radially outward.

Answer:

Potential Due to a Charged Conducting Sphere:

Consider a conducting sphere with a total charge Q and radius R.

To find electric potential (V) at points both inside and outside the sphere.

- Inside the Sphere:

Inside the conducting sphere, the charge Q is uniformly distributed over the entire volume. Let's consider a point inside the sphere at a radial distance r from the center, where $r \leq R$.

To find the potential inside the sphere, we can use the formula for the potential due to a point charge $\left(V = \frac{kQ}{r}\right)$, where r is the distance from the center to the point inside the sphere.

$\Rightarrow \quad V_{\text{inside}} = \frac{kQ}{r}$

- Outside the Sphere:

Outside the conducting sphere (i.e., for r > R), we can treat the entire charge Q as if it were concentrated at the center of the sphere. This is because the electric field outside a charged spherical shell is the same as that of a point charge located at the center.

Thus, for r > R, the potential is given by:

$\Rightarrow \quad V_{\text{outside}} = \frac{kQ}{r}$

Behavior of Potential as One Moves Radially Outward:

Inside the Sphere (r ≤ R):

- The potential (V) inside the sphere decreases as the distance from the center increases (r increases).
- It follows an inverse relationship with r, similar to the potential due to a point charge.

Outside the Sphere (r > R):

- The potential (V) outside the sphere also decreases as the distance from the center increases (r increases).
- It behaves as if all the charge is concentrated at the center of the sphere, following an inverse relationship with r.

At the Surface of the Sphere (r = R):

- The potential is continuous across the surface of the conducting sphere.
- The potential at the surface is the same whether calculated from the inside or the outside expressions.

This behavior is consistent with the fact that inside a uniformly charged conducting sphere, the electric field is zero, and the potential is constant. Outside the sphere, the potential behaves as if all the charge is concentrated at the center, resulting in an electric field that decreases with distance.

63. Discuss the phenomenon of energy loss in dielectrics. Explain the concept of dielectric strength and its role in preventing dielectric breakdown.

Answer:

Energy Loss in Dielectrics:

Dielectrics are insulating materials that are commonly used in capacitors to store electrical energy. When an electric field is applied across a dielectric material, it undergoes polarization—alignment of the electric dipoles within the material. This process involves the reorientation of molecules or atoms in response to the external electric field.

Energy is lost in dielectrics due to several factors like Dielectric Hysteresis, Molecular Friction, Dielectric Strength.

Factors Influencing Dielectric Strength:

Dielectric strength depends on the nature of the dielectric material, its thickness, and the rate of voltage application. The key factors include:

- Material Properties: Different materials have different dielectric strengths. For example, air has a lower dielectric strength than many solid insulators.
- Thickness: Thicker insulating materials generally have higher dielectric strength.
- Rate of Voltage Application: Rapid changes in voltage can reduce dielectric strength. This is often a concern in high-frequency applications.

Role in Preventing Dielectric Breakdown: Dielectric strength is crucial in preventing dielectric breakdown, which occurs when the electric field becomes too strong, leading to a sudden increase in current flow through the dielectric. This breakdown can result in the permanent damage of the dielectric material.

- Insulation in Electrical Devices: Dielectric strength is a critical parameter in the design and manufacturing of electrical devices, especially those using capacitors and insulating materials.

Ensuring a sufficient dielectric strength helps prevent unintended breakdown, which can lead to electrical failure and safety hazards.

- Safety in High Voltage Applications: In high-voltage systems, such as power transmission lines and transformers, dielectric strength is essential for maintaining the integrity of insulating materials under intense electric fields.

17

Electric current

Short summary

What do we learn

Quick Revision

➢ *Current electricity*

The study of charges at rest is called electrostatics while **"The study of charges in motion is called current electricity (electric current).**

Simply, **"the rate of flow of charge in per unit time is called electric current."**

$$\boxed{I = \frac{Q}{T}}$$

Where **Q** is the charge that flows across the given area in time **T**.

- Current is denoted by 'I'.
- S.I. Unit of current is Ampere (A).
- Dimensional formula is $[A]^1$.
- Current is a scalar quantity.

➢ *Instantaneous current*

If the rate of flow of charge varies with time, the current also varies with time.

It is expressed as: $\boxed{I = \frac{dQ}{dt}}$

➢ *Average current*

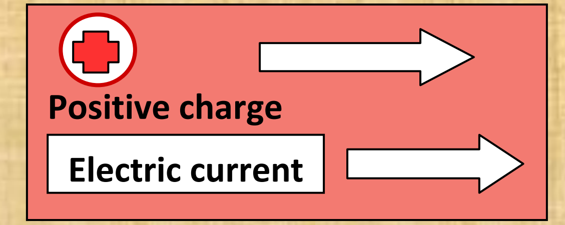
If charge Δq flows in time Δ*t*, the average current is defined as:

$$\boxed{I_{Av} = \frac{dQ}{dt}}$$

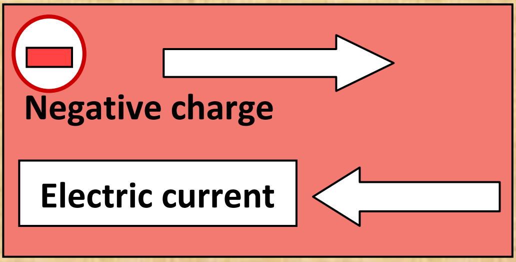
➢ *Convention and electronic current & direction of current*

The direction of electric current is same as that of positive charge and opposite to direction of negative charge or electron.

Before invention



After invention



Note: In any circuit the current is assumed to flow from the positive end to negative end.

➢ *Current has direction but it is a scalar quantity, why?*

Current is a scalar quantity even through it has magnitude as well as direction but it doesn't obey vector law of addition.

Current density

It tells about the amount of charge flowing per unit area and about the direction of the current.

$$\boxed{j = \frac{I}{A}}$$

- Current density is a vector quantity.
- It is denoted by j.
- S.I. unit is A/m^2.

Ohm's law

According to Ohm's law, "**the electric current through a conductor is directly proportional to the potential difference across it, provided the physical conditions such as temperature and pressure remain unchanged.**"

It can be written as:

$$V \propto I$$

$$\Rightarrow \boxed{V = RI}$$

Where R is constant of proportionality is called Resistance.

Resistance: It is the property of a conductor by virtue of which it opposes the rate of flow of current.

$$\boxed{R = \frac{V}{I}}$$

- Its SI unit of resistance is ohm (Ω).
- The I–V graph for a metallic conductor is a straight line.

Resistance and resistivity

Resistance is depends on

- Nature of conductor
- Dimension of conductor (length and cross sectional area).

$$R \propto \frac{l}{A}$$

$$\Rightarrow \boxed{R = \rho\,\frac{l}{A}}$$

Where ρ is constant of proportionality is called Resistivity.

$$\boxed{\rho = \frac{RA}{l}}$$

- S.I. unit of ρ is ohm.meter

Grouping of resistance

There are two ways in common use to combine or grouping so many Resistors in one circuit which are –:

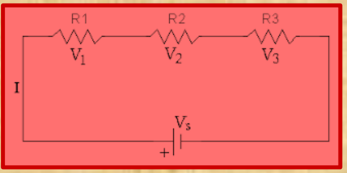
(i) Series grouping

(ii) Parallel grouping

Series grouping of resistance

A series combination of resistors is in which resistors are arranged in a single chain.

- Joining them end to end

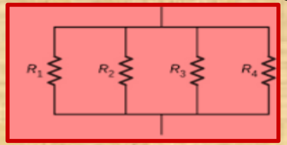


Equivalent resistance (R_{eq}) is given as:

$$\boxed{R_{eq} = R_1 + R_2 + R_3 + \dots R_n}$$

➢ Parallel grouping of resistance

A parallel combination of resistors is in which resistors are arranged with their heads connected together and their tails connected together.



Equivalent resistance is given by:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

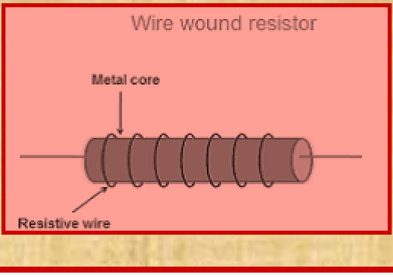
➢ Types of resistors

There are mainly two types of resistors –:

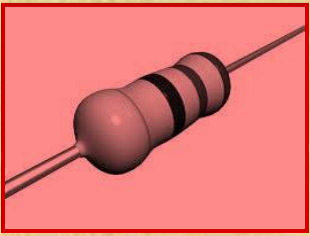
1. Wire wound resistors
2. Carbon resistors

➢ Wire wound resistors

- Wire wound resistors are made up of alloys.
- Wires of alloy are wound over and over again to form a resistor.
- They are used in car braking system, railway track system etc .
- Wire wound resistors are old and they are less useful as compare to carbon resistors.



➢ Carbon resistors



- Carbon resistors are made up of carbon compound.
- They are widely used in electronic materials because they are small in size and inexpensive.
- Carbon resistors have different colour bands or colour rings in different patterns.
- To know the value of resistance of a resistor **Colour coding** is done.

$$\mathbf{R = AB \times 10^{C}\,\Omega \pm D}$$

➢ Temperature dependence of resistors

The resistivity of conductor depends on temperature as follow –:

(i) For most of metals, resistivity is increases as temperature increases.

(ii) The resistivity of alloys also increases with increase in temperature.

(iii) The resistivity of semiconductors usually decreases with increase in temperature.

Electromotive force (EMF) and potential difference

EMF (E) of a cell or battery equals the potential difference between its terminals when these are not connected (open circuit) externally, i.e. when no current is flowing through the cell.

$$\boxed{E = V + Ir}$$

Where E = EMF, V = Potential difference, I = Current, r = internal resistance

Chemical cells: primary and secondary

To pass current through the conductor we have to maintain potential difference and for this purpose device is used is called chemical cells.

Primary cell

- In these cells chemical energy is directly converted into electrical energy.

- It cannot be recharged and reused.

- Examples –: Dry cell, Daniel cell, voltaic cell etc.

Secondary cell

- In these cells electrical energy is derived from the reversible chemical reaction.

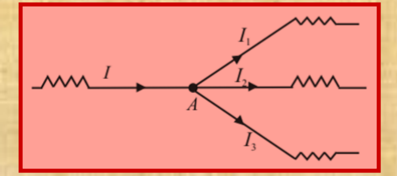
- They need to be recharged when the charge gets over.

- Examples –: Acid-accumulator, Battery of inverter or car,

Kirchhoff's rule

Kirchhoff had given two laws which are very helpful for us to calculate I, E R and so on.

Kirchhoff's first rule (junction law)

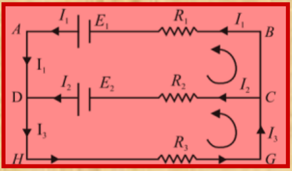


According to this law **Sum of currents coming to a junction is equal to the sum of currents going away from it.**

$$\boxed{I = I_1 + I_2 + I_3}$$

- The algebraic sum of all currents at a junction is zero.
- Incoming current is taken as positive & outgoing current is taken as negative.
- It is based on the law of conservation of charge.

Kirchhoff's second rule (loop law)



This law states that **"In a closed loop, algebraic sum of EMFs is equal to the algebraic sum of product of resistances and respective current flowing through them."**

➢ More about loop law

Mathematically, we can write

$$\sum IR = \sum E$$

- The algebraic sum of all the potential differences along a closed loop in a circuit is zero.
- Voltage drop in the direction of current is positive and in the opposite direction of current is negative.
- EMF of cell is taken as +ve if we met +ve plate first and vice – versa.
- It is based on the law of conservation of energy.

➢ Wheatstone bridge

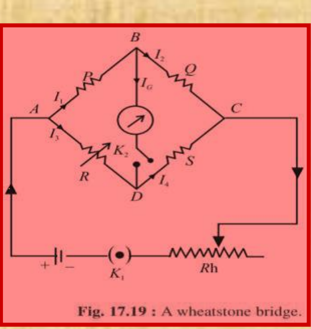


Fig. 17.19 : A wheatstone bridge.

Wheatstone bridge is a special arrangement of four resistors as shown in fig. by which we can measure the unknown resistance with the help of other three resistances.

$$\frac{P}{Q} = \frac{R}{S}$$

➢ Potentiometer

It is a device which is used to measure the potential difference between two points more accurately.

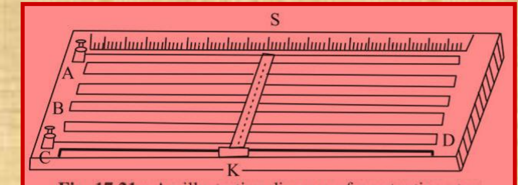


Fig. 17.21 : An illustrative diagram of a potentiometer

$$v = \frac{E}{l}\, l_1$$

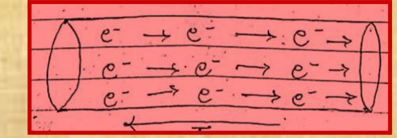
Applications of potentiometer

1. Used to compare two EMF of cell.

2. Used to find the internal resistance of the cell

3. Used to find the EMF of cell

➢ Drift velocity of electrons



The velocity with which the free electrons are drifted towards the positive terminal, under the action of the applied field, is called the drift velocity of the free electrons.

$$V_d = \left(\frac{eV}{ml}\right)T$$

Here, e is the charge of electron, V is the potential difference, m is the mass and T is relaxation time.
Electric current and drift velocity

$$I = \frac{q}{T} = nAve$$

Question – Answer

① MCQs

1. What is the order of magnitude of the resistance of a dry human body?

(A) 10 Ω (B) 10^4 Ω (C) 10 MΩ (D) 10 μΩ

Answer: (b) 10^4 Ω

2. A silver wire has a resistance of 2.1 Ω at 27.5 °C, and a resistance of 2.7 Ω at 100 °C. What is the temperature coefficient of resistivity of silver?

(A) 0.0059 (B) 0.0039 (C) 0.0129 (D) 0.0159

Answer: (B) 0.0039

3. The rate of flow of electric charge through any cross-section of a conductor is known as __________.

(A) Electric flux (B) Electric potential

(C) Electric current (D) Electric field

Answer: (C) Electric current

4. Which of the following is non – ohmic resistance?

(A) Lamp filament (B) Copper wire

(C) Carbon resistor (D) Diode

Answer: (D) Diode is non – ohmic resistance.

5. Unit of conductance is:

(A) Dyne (B) Siemen (C) Ohm (D) Volts

Answer: (B) Siemen

6. Current density is a :

(A) Scalar quantity (B) vector quantity

(C) Dimensionless quantity (D) none of these options

Answer: (B) vector quantity.

7. The resistivity of certain metals or alloys drops to zero when they are cooled below a certain temperature, this phenomenon is known as:

(A) Conductivity (B) Partial conductivity
(C) Superconductivity (D) Non-conductivity

Answer: (C) Superconductivity

8. The opposition offered by the electrolyte of the cell to the flow of current through itself is known as:

(A) External resistance (B) Internal resistance
(C) Non-resistance (D) None of these options

Answer: (B) Internal resistance

9. Which of these is a correct definition of conventional current?

(A) Current that flows from lower potential to higher potential
(B) The current which remains static
(C) Current constituted by the flow of ions
(D) Current that flows from higher potential to lower potential

Answer: (D) Current that flows from higher potential to lower potential

10. On increasing temperature, the resistivity of: [PYQ NIOS April 2022]

(A) A conductor decreases, but that of an insulator increases.
(B) A conductor increases but that of an insulator increases.
(C) Conductor and insulator both decreases.
(D) Conductor and insulator both decreases.

Answer: (D) Conductor and insulator both decreases.

11. Which type of current is flowing through a circuit?

(A) Static current (B) Conventional current
(C) Electronic current (D) Potential current

Answer: (C) Electronic current

12. Identify the dimensional formula of electric current:

(A) $[M^1 L^1 T^{-2}]$ (B) $[M^0 L^0 T^0 A^1]$
(C) $[M^1 L^3 T^0]$ (D) $[M^1 L^2 T^{-3}]$

Answer: **(B) [M^0 L^0 T^0 A^1]**

13. **Which type of a physical quantity is electric current?**

(A) Scalar quantity (B) Vector quantity
(C) Bipolar quantity (D) Thermodynamic quantity

Answer: **(A) Scalar quantity**

14. **How many different resistances are possible with two equal resistors?**

(A) 2 (B) 3 (C) 4 (D) 5

Answer: **(B) 3**

15. **Which of the following has maximum resistance?**

(A) Galvanometer (B) Miliammeter (C) Ammeter (D) Voltmeter

Answer: **(D) Voltmeter** **[PYQ NIOS April 2022]**

16. **Specific resistance of all metals is mostly affected by:**

(A) temperature (B) pressure (C) magnetic field (D) volume

Answer: **(A) temperature**

17. **According to Kirchhoff's law, in any analytical circuit, if the direction of current is assumed opposite, then the value of current will be:**

(A)–i (B) i (C) 2i (D) 0

Answer: **(A) -i**

18. **Ohm's Law relates:**

(A) Voltage and Current (B) Current and Resistance
(C) Voltage and Resistance (D) Charge and Time

Answer: **(C) Voltage and Resistance**

19. **The resistance of a wire depends on its:**

(A) Length and Area (B) Length and Temperature
(C) Temperature and Area (D) Length, Area, and Temperature

Answer: **(A) Length and Area**

20. **The electrical energy consumed by an appliance is calculated using the formula:**

(A) Power = Voltage × Current
(B) Power = Current × Resistance
(C) Power = Voltage² / Resistance
(D) Power = Current² × Resistance

Answer: **(D) Power = Current² × Resistance**

21. **The resistance of a wire depends on its:**

(A) Length and Area
(B) Length and Temperature
(C) Temperature and Area
(D) Length, Area, and Temperature

Answer: **(A) Length and Area**

22. **The electrical energy consumed by an appliance is calculated using the formula:**

(A) Power = Voltage × Current
(B) Power = Current × Resistance
(C) Power = Voltage² / Resistance
(D) Power = Current² × Resistance

Answer: **(D) Power = Current² × Resistance**

② complete the sentence using an appropriate word:

23. **One volt, watt, junction law, ammeter, conductivity**

(1) The reciprocal of resistivity is known as ……………….
(2) The SI unit of electric power is ……………….
(3) The instrument used to measure electric current is called ……………….
(4) The potential difference required to produce a unit current in a circuit is defined as ……………….
(5) Kirchhoff's first law, also known as the ………………. , states that the total current entering a junction is equal to the total current leaving the junction.

Answer: **(1) conductivity (2) watt (3) Ammeter (4) one volt (5) junction law**

③ Fill in the blanks

24. **[Sample paper]**

(i) Kirchhoff' s first law for electric network is based on **…………..**

(ii) Kirchhoff' s second law for electric network is based on **……………….**

(iii) EMFs of two cells can be compared by using **……………….**

(iv) Meter bridge works on the principle of **……………….**

Answer: **(i) law of conservation of charge, (ii) law f conservation of energy, (iii) potentiometer, (iv) wheatstone bridge**

25.

(i) In a series circuit, the total resistance is equal to **……………….**

(ii) The resistance of a wire is directly proportional to its length and inversely proportional to its **……………….**

(iii) The potential difference across a conductor is measured in **……………….**

(iv) In a closed loop of an electrical circuit, the algebraic sum of the potential differences is equal to the sum of the **……………….**

(v) The sum of the products of the resistances and currents in each branch of a network is equal to the total **……………….** in the network.

(vi) The loop in Kirchhoff's second law is also referred to as a **……………….** in the circuit.

(vii) Kirchhoff's laws are based on the principles of conservation of **……………….** and conservation of **……………….**

Answer: **(i) The sum of individual resistances, (ii) Cross-sectional area, (iii) volts, (iv) Electromotive Forces (emfs), (v) Voltage (potential difference), (vi) Mesh, (vii) charge, energy**

④ True or false

26. The total resistance in the series combination is more than the greatest resistance in the circuit.

Answer: True

27. In electrolytes and ionic crystals, the current carriers are free electrons.

Answer: False.

28. According to Kirchhoff's first law, the algebraic sum of currents meeting at any junction in an electric circuit is zero.

Answer: False.

29. In a series circuit, the potential difference across each resistor is the same.

Answer: True.

30. The total resistance in a parallel circuit is equal to the sum of individual resistances.

Answer: False.

31. A superconductor has infinite resistivity.

Answer: False.

32. The drift velocity of electrons in a conductor is inversely proportional to the cross-sectional area of the conductor.

Answer: False.

33. Kirchhoff's second law is also known as the Law of Current Conservation.

Answer: False.

34. The unit of electrical power is joule per coulomb.

Answer: False.

35. The resistance of a wire is directly proportional to its length and inversely proportional to its resistivity.

Answer: True.

36. In a circuit, if the potential difference increases, the current must also increase.

Answer: False.

37. An ideal ammeter has infinite resistance.

Answer: False.

38. The direction of conventional current is opposite to the direction of electron flow.

Answer: True.

39. The resistivity of a material depends on its temperature.

Answer: True.

40. The reciprocal of resistivity is resistance.

Answer: False.

⑤ Match the following

Column I	Column II
(i) Ohm's law	(a) Resistance is inversely proportional to temperature
(ii) Superconductors	(b) Materials with zero resistance at extremely low temperatures.
(iii) Semiconductor	(c) V = IR; relationship between voltage, current, and resistance.
(iv) Negative temperature coefficient	(d) Materials with conductivity between conductors and insulators.

Answer: **(i) – (c), (ii) – (b), (iii) – (d), (iv) – (a)**

⑥ Very short type answer question [2 marks of each]

41. **In a circuit with multiple resistors, how does the equivalent resistance change when a resistor is connected in parallel with the existing resistors?**

Answer: The equivalent resistance decreases when a resistor is added in parallel because parallel resistors offer more pathways for current, reducing overall resistance.

42. **Explain the concept of drift velocity in the context of current electricity.**

Answer: Drift velocity is the average velocity of charged particles due to an applied electric field. It's small because frequent collisions with atoms hinder constant acceleration.

43. Differentiate between the drift velocity and the conventional current in a metallic conductor.

Answer: Drift velocity is the actual speed of charged particles, while conventional current is the hypothetical flow of positive charges in the opposite direction.

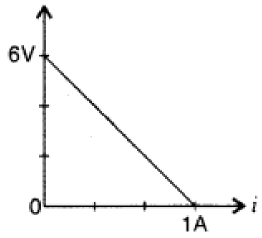
44. How does the resistance of a metallic conductor change with temperature?

Answer: In most cases, the resistance of a metallic conductor increases with temperature due to heightened atomic vibrations impeding the flow of electron.

45. Describe the effect of increasing the length of a wire on its resistance.

Answer: Resistance is directly proportional to the length of a wire. Doubling the length doubles the resistance, assuming constant cross-sectional area and material.

46. The plot of the variation of potential difference across a combination of three identical cells in series, versus current is as shown in the figure. What is the emf of each cell?

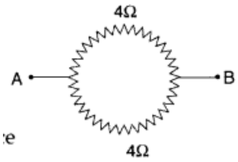


Answer:

Total emf of three cells in series = P.D corresponding to zero current = 6V

The emf of each cell = $\frac{6}{3}$ = 2V

47. A wire of resistance 8R is bent in the form of a circle. What is effective resistance between the ends of a diameter 2AB?

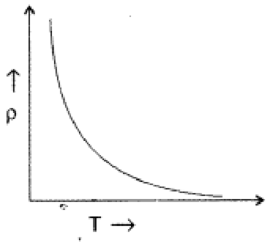


Answer: The effective resistance between A and BO

$$R_{eff} = \frac{4R \times 4R}{4R + 4R} = \frac{16R^2}{8R} = 2R$$

48. **Show on a graph the variation of resistivity with temperature for a typical semiconductor.**

Answer:



Resistivity of a semi conductor decreases rapidly with temperature.

49. **Define the term 'Mobility' of charge carriers in a conductor. Write its S.I. unit.**

Answer: Mobility of charge carriers is defined as the magnitude of the drift velocity per unit electric field E.

$$\therefore \quad \mu = \left|\frac{V_d}{E}\right| = \frac{e\tau}{m}$$

50. **State the underlying principle of a potentiometer.**

Answer: When a constant current flows through a wire of uniform cross – section and of uniform composition, the potential difference across any length of wire is directly proportional to its length, i.e., $V \propto l$

⑦ Short type answer question [3 marks of each]

51. **Derive an expression for the resistivity of a good conductor, in terms of the relaxation time of electrons.**

Answer: Drift speed gained by an electron under the effect of electric field $\vec{E}$ in a conductor is

$$v_d = \frac{eE}{m}\tau$$

$$v_d = \frac{eV}{ml}\tau \qquad \ldots\left(\because E = \frac{V}{l}\right)$$

We have relation, $I = neAv_d$

$$I = neA\left(\frac{eV}{ml}\tau\right), \quad R = \frac{V}{I} = \frac{ml}{ne^2\tau A} \Rightarrow R = \rho\frac{l}{A}$$

$$\frac{ml}{ne^2\tau A} = \rho\frac{l}{A}$$

$\rho = \frac{m}{ne^2\tau}$ between resistivity and relaxation time of electrons.

52. Using the mathematical expression for the conductivity of a material, explain how it varies with temperature for

(i) semiconductors,

(ii) good conductors.

Answer:

Conductivity $\sigma = \frac{ne^2r}{m}$

(i) Semiconductors: With increase in temperature, conductivity of semiconductor increases. It is due to increase in V. It dominates the effect caused by decrease in 'x'.

(ii) Good conductors : With increase in temperature, conductivity of good conductors decreases. It is due to decrease in the value of relaxation time. The effect of increased value of V is negligible.

53. The EMF of a cell is 5.0 V . When it is connected across a resistor of 4.5 Ω , the potential drop across the resistor is found to be 3.0 V . Calculate the internal resistance of the cell. **[PYQ NIOS Jan 2021]**

Answer: iR = E – ir -------------- (1)

The value of iR is given as 3V

iR = 3V -------------- (2)

i = 3/R -------------- (3)

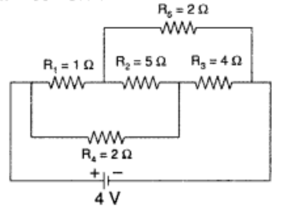
Putting the values in 1

$3 = 5 - 3r/R$

$2 = 3r/4.5$

$\Rightarrow r = 3\Omega$

54. Calculate the current drawn from the battery in the given network.



Answer: Since $\frac{R_5}{R_1} = \frac{R_3}{R_4}$, the current through $R_2 = 5\ \Omega$ is zero and so is electrically absent.
(R_1, R_5) and (R_3, R_4) are in series to give $3\ \Omega$ and $6\ \Omega$ respectively. They are themselves in parallel to form

$$R_{eq} = \frac{3 \times 6}{3 + 6} = \frac{18}{9} = 2\ \Omega$$

$\therefore$ Current drawn from the battery,

$$I = \frac{V}{R_{eq}} = \frac{4}{2} = \mathbf{2\ A}$$

55. An ammeter of resitance 1 Ω can measure current upto 1.0 A

(i) What must be the value of the shunt resistance to enable the ammeter to measure upto 5.0 (A)?

(ii) What is the combined resistance of the ammeter and the shunt?

Answer: (*i*) Shunt Resistance, $S = \frac{R_A i_g}{i - i_g} = \frac{1 \times 1}{5 - 1} = \mathbf{0.25\ \Omega}$

(*ii*) Total Resistance, $\frac{1}{R_{total}} = \frac{1}{0.25} + \frac{1}{1} = 5$

$$\therefore\ R_{total} = \frac{1}{5}\ \Omega = \mathbf{0.2\ \Omega}$$

56. State Kirchhoff's rules. Explain briefly how these rules are justified.

Answer: Kirchhoff's rules –:

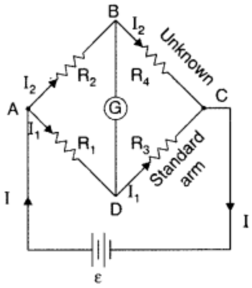
Kirchhoff's junction rule : At any junction, the sum of the currents entering the junction is equal to the sum of currents leaving the junction.

Kirchhoff's loop rule : The algebraic sum of changes in potential in any closed loop involving resistors and cells is zero.

These two laws are justified on the basis of law of conservation of charge and the law of conservation of energy respectively.

57. Use Kirchhoff's rules to obtain conditions for the balance condition in a Wheatstone bridge.

Answer: Conditions for the balance condition in a Wheatstone bridge:



Applying Kirchhoff's loop rule to closed loop ADBA,

$$-I_1R_1 + 0 + I_2R_2 = 0 \qquad (I_g = 0) \qquad \ldots(i)$$

For loop CBDC,

$$-I_2R_4 + 0 + I_1R_3 = 0 \qquad (I_g = 0) \qquad \ldots(ii)$$

From equation, (i)

$$\frac{I_1}{I_2} = \frac{R_2}{R_1}$$

From equation, (ii)

$$\frac{I_1}{I_2} = \frac{R_4}{R_3} \qquad \therefore \frac{R_2}{R_1} = \frac{R_4}{R_3} \quad \text{or} \quad \frac{R_1}{R_2} = \frac{R_3}{R_4}$$

This is the required balance condition in a Wheatstone bridge arrangement.

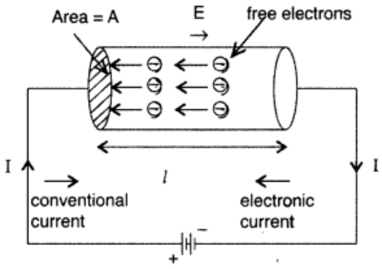
⑧ Long type answer question [4 marks of each]

58. Prove that the current density of a metallic conductor is directly proportional to the drift speed of electrons.

Or

Derive an expression for the current density of a conductor in terms of the drift speed of electrons.

Answer: Suppose a potential difference V is applied across a conductor of length l and of uniform cross-section A. The electric field E set up inside the conductor is given by: E = VI



Under the influence of field E→, the free electrons begin to drift in the opposite direction E→ with an average drift velocity v_d.

Let the number of electrons per unit volume or electron density = n

Charge on an electron = e

No. of electrons in length l of the conductor = n x volume of the conductor = n × Al

Total charge contained in length l of the conductor is q = enAl … (i)

All the electrons which enter the conductor at the right end will pass through the conductor at the left end in time,

$$t = \frac{\text{distance}}{\text{velocity}} = \frac{l}{v_d} \qquad \dots (ii)$$

Using equations (i) and (ii), we get

$$\text{Current I} = \frac{q}{t} = \frac{l\,ne\,\text{A}}{l\,/\,v_d} = neAv_d$$

Current density 'J' is given by

$$\text{J} = \frac{\text{I}}{\text{A}} = \frac{neAv_d}{A} = nev_d \qquad \therefore \text{J} \propto v_d$$

Hence the current density of a metallic conductor is directly proportional to the drift speed of electrons.

59. **Two resistances R_1 and R_2 are connected with a battery of V volts. Compute the net resistance, when they are connected first (a) in series and then (b) in parallel. Draw circuit diagrams for each.**

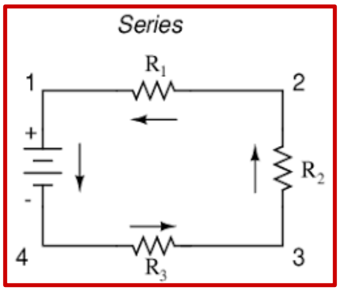
[PYQ NIOS Oct 2021]

Answer:

(a) Series Connection: When resistances are connected in series, the total resistance (R_{total}) is the sum of the individual resistances.

$$R_{total} = R_1 + R_2 + R_3 + \dots R_n$$

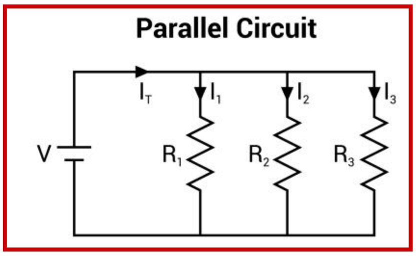
Circuit Diagram for Series Connection:



(b) Parallel Connection: When resistances are connected in parallel, the reciprocal of the total resistance (R_{total}) is the sum of the reciprocals of the individual resistances.

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots\ldots + \frac{1}{R_n}$$

Circuit Diagram for Parallel Connection:


Parallel Circuit

60. **Derive an expression for the drift velocity of conduction electrons, when electric field is applied.** **[PYQ NIOS Oct 2021]**

Answer: When conductor is subjected to an electric field E, each electron experience a force

F = −eE and acquires an acceleration of $a = \frac{F}{m} = -\frac{eE}{m}$ ..... (1)

The average time difference between two consecutive collisions is known as relaxation time of electron.

$$\tau = \frac{\tau_1 + \tau_2 + \tau_3 + \cdots + \tau_n}{n} \qquad \ldots\ldots(2)$$

As v = u + at then drift velocity v_d is

$$v_d = \frac{v_1 + v_2 + v_3 + \cdots + v_n}{n}$$

$$v_d = \frac{(u_1 + u_2 + u_3 + \cdots + u_n) + a(\tau_1 + \tau_2 + \tau_3 + \cdots + \tau_n)}{n}$$

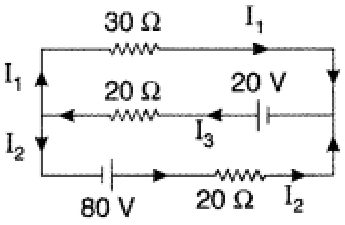
$$v_d = \frac{(o) + a(\tau_1 + \tau_2 + \tau_3 + \cdots + \tau_n)}{n}$$ {since initial velocity is zero}

$$V_d = 0 + a\tau$$

$$\boldsymbol{v_d = -\frac{eE}{m}\tau}$$

According to drift velocity expression, the relaxation time is the time interval between successive collisions of an electron on increasing temperature, the electrons move faster and more collisions occur quickly. Hence, relaxation time decreases with increase in temperature which implies that drift velocity also decreases with temperature.

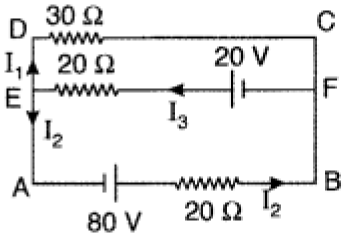
61. **Use Kirchhoff's rules to determine the value of the current I_1 flowing in the circuit shown in the figure.**


30 Ω
I_1
I_1
20 Ω
20 V
I_2
I_3
80 V
20 Ω
I_2

Answer: Using Kirchoff's first law at junction E, we get

$$I_3 = I_3 + I_2$$

In loop ABCDA, using Kirchoff's second law, we get


D
30 Ω
C
I_1
20 Ω
20 V
E
F
I_3
I_2
A
B
80 V
20 Ω
I_2

$$80 - 20\ I_2 + 30\ I_1 = 0$$

$\Rightarrow\ 2\ I_2 - 3\ I_1 = 8$ [÷ by 10] ...(*ii*)

In loop ABFEA, we get

$$80 - 20\ I_2 + 20 - 20\ I_3 = 0$$

$\Rightarrow\ I_2 + I_3 = 5$ [÷ by 20] ...(*iii*)

Putting the value of I_3 into (*iii*), we have

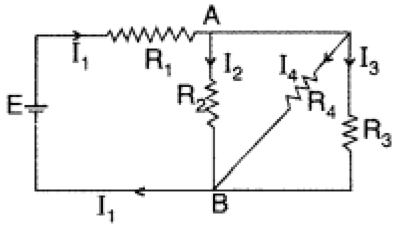
$I_2 + (I_1 + I_2) = 5 \Rightarrow 2\ I_2 + I_1 = 5$ ...(*iv*)

Solving equations (*ii*) and (*iv*), we get

$$I_1 = -\frac{3}{4}\text{A} = -0.75\ \text{A}$$

So (-) sign of current indicates that the direction of current is opposite to that as shown in the circuit diagram.

62. **In the circuit shown, R_1 = 4Ω, R_2 = R_3 = 15 Ω, R_4 = 30Ω and E = 10V. Calculate the equivalent resistance of the circuit and the current in each resistor.**


A
I_1
R_1
I_2
I_4
I_3
E
R_2
R_4
R_3
I_1
B

Answer:

As clear from the given figure
R_3 and R_4 are in parallel combination, hence their resultant will be

$$\frac{1}{R_{34}} = \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{15} + \frac{1}{30} = \frac{2+1}{30} = \frac{3}{30} = \frac{1}{10}$$

i.e., $R_{34} = \mathbf{10\ \Omega}$

Now R_{34} and R_2 are again in parallel combination

$$\therefore \quad \frac{1}{R_{234}} = \frac{1}{R_{34}} + \frac{1}{R_2} = \frac{1}{10} + \frac{1}{15}$$

$$= \frac{15+10}{150} = \frac{25}{150} = \frac{1}{6} \qquad \therefore\ \mathbf{R_{234} = 6\ \Omega}$$

Finally R_{234} and R_1 are in series combination

$$R_{1234} = R_{234} + R_1 = 6 + 4 = \mathbf{10\ \Omega}$$

$$\therefore \quad I = \frac{V}{R} = \frac{10}{10} = 1\text{A}$$

$\therefore \quad I_1 = \mathbf{1A} \qquad\qquad I_1 = I_2 + I_3 + I_4$

Potential at R_1, $V_1 = I_1R_1 = 1 \times 4 = \mathbf{4\ volt}$

Potential at R_2, R_3 and R_4, $V_{234} = 1 \times 6 = \mathbf{6\ volt}$

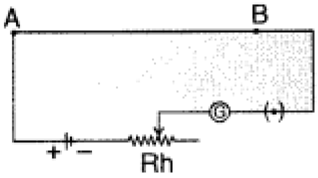
$$\therefore \quad I_2 = \frac{6}{15} = \frac{2}{5}\text{A} \quad I_3 = \frac{6}{15} = \frac{\mathbf{2}}{\mathbf{5}}\mathbf{A},\ I_4 = \frac{6}{30} = \frac{\mathbf{1}}{\mathbf{5}}\mathbf{A}$$

⑨Very Long type answer question [5 marks of each]

63. State the principle of a potentiometer. Describe briefly, with the help of a circuit diagram, how this device is used to compare the emf’s of two cells.

Answer:

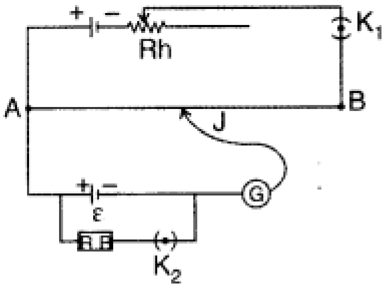
Potentiometer: A potentiometer is a device used to measure potential difference.



Principle: The basic principle of a potentiometer is that when a constant current flows through a wire of uniform cross-sectional area and composition, the potential drop across any length of the wire is directly proportional to that length.

$V \propto l \qquad V = Kl$

Close the key K_1. A constant current flows through the potentiometer wire. With key K_2 kept open, move the jockey along AB till it balances the emf e of the cell. Let l, be the balancing length of the wire. If K is the potential gradient, then emf of the cell will be



$$\varepsilon = kl_1 \qquad \text{............ (i)}$$

With the help of resistance box R. B, introduce a resistance R and close key K_2. Find the balance point for the terminal potential difference V of the cell. If l_2 is the balancing length, then

$$V = kl_2 \qquad \text{......... (ii)}$$

Dividing (*ii*) by (*i*), we have $\frac{\varepsilon}{V} = \frac{Kl_1}{Kl_2} = \frac{l_1}{l_2}$

Let r be the internal resistance of the cell ε = I (R + r) and V = IR.

64. Consider a circuit with multiple resistors connected in a Wheatstone bridge configuration. Discuss the conditions under which the bridge is balanced, and derive the formula for the unknown resistance in terms of the known resistances when the bridge is balanced.

Answer: The Wheatstone bridge is a circuit configuration commonly used for measuring resistance. It consists of four resistors arranged in a diamond shape, with a voltage source applied across the top and bottom of the diamond. The bridge is considered balanced when the ratio of the resistances in one arm is equal to the ratio in the opposite arm.

∗ The conditions for the Wheatstone bridge to be balanced are:

- Ratio Condition:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

This ensures that the potential difference across the bridge is zero, and no current flows through the galvanometer.

- Null Current Condition:

The galvanometer current (I_g) should be zero, indicating that the bridge is balanced.

∗ Derivation of the Formula for Unknown Resistance (R_x):

Consider the Wheatstone bridge with the known resistances R_1 , R_2, R_3, and an unknown resistance R_n. Let V be the potential difference across the bridge, and I be the current through the bridge.

Using Kirchhoff's voltage law in the closed loop:

$$V = I.\, R_1 + I.\, R_x \quad \text{.......} \ (1)$$

In the balanced condition, the potential difference across the bridge is zero:

$$V = 0 \qquad \text{.........} \ (2)$$

From equations (1) and (2), we can write:

$$I.\, R_1 + I.\, R_x = 0$$

Solving for R_x:

$$R_x = -\, R_1 \qquad \text{..........} \ (3)$$

The negative sign indicates that R_x is in the opposite arm compared to R_1. To remove the negative sign, we can rewrite equation (3) as:

$$R_x = -\frac{R_1.R_3}{R_2} \qquad \text{...........} \ (4)$$

This is the formula for the unknown resistance (R_X) in terms of the known resistances when the Wheatstone bridge is balanced.

65. **a) Three resistors 1 Ω, 2 Ω, and 3 Ω are combined in series. What is the total resistance of the combination?**

b) If the combination is connected to a battery of emf 12 V and negligible internal resistance, obtain the potential drop across each resistor.

Answer:

(a) We know that resistors $r_1 = 1\ \Omega$, $r_2 = 2\ \Omega$ and $r_3 = 3\ \Omega$ are combined in series.

$$\text{In series, } R_{Total} = r_1 + r_2 + r_3$$

$$R_{Total} = 1\ \Omega + 2\ \Omega + 3\ \Omega = 6\ \Omega$$

(b) Potential drop across each resistor

When resistors are in series, the potential drop across each resistor is proportional to its resistance. The potential drop (V_i) across a resistor R_i can be calculated by using Ohm's law

$$V_i = I.\,R_i$$

In a series circuit, the current (I) remains constant across all resistors. To find I, we can use ohm's law for the circuit.

$$V_{total} = I.\,R_{total} \Rightarrow I = \frac{V_{total}}{R_{total}}$$

Given: $V_{total} = 12\ V$ & $R_{total} = 6\ \Omega$

Substitute the value as: $I = \frac{12}{6} = 2A$

Now, we can find the potential drop across each resistor:

$$V_1 = I.\,R_1 = 2A \times 1\ \Omega = 2V$$

$$V_2 = I.\,R_2 = 2A \text{ x } 2\ \Omega = 4\ V$$

$$V_3 = I.\,R_3 = 2A \text{ x } 3\ \Omega = 6\ V$$

17

Magnetism and magnetic effect of electric current

Short summary

What do we learn

Quick Revision

➢ *Magnet*

Magnet is an object that attracts objects made of iron, cobalt and nickel. Magnet comes to rest in north – south direction, when suspended freely.

*** Types of artificial magnet**

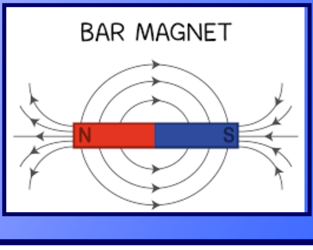
Magnet needle

Bar magnet

Magnet compass

➢ *Bar Magnet*

A Rectangular object that have magnetic field. A magnet has always two poles namely as **North Pole** and **South Pole**.



➢ *Use of magnet*

Magnets are used in many appliances some of them are following –:

- In refrigerators
- In radio and stereo speakers
- In children's toys and
- On hard discs and floppies computers.

➢ *Properties of magnet*

- A free suspended magnet always points towards the north and south direction.
- The pole of a magnet which point toward north direction is called North Pole or north – seeking.
- The pole of a magnet which point toward south direction is called South Pole or south – seeking.
- Like poles of magnets repel each other while unlike poles of magnets attract each other.
- The poles of a magnet are inseparable. In a bar magnet, isolated poles do not exist. It has always two poles.

➢ *Magnetic field*

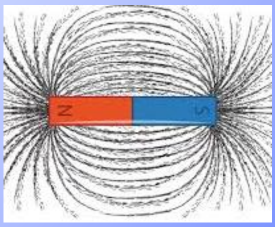
The area around a magnet where a magnetic force is experienced is called the magnetic field.

It is a vector quantity that has both direction and magnitude.

The magnetic field is represented by magnetic field lines.

Magnetic field lines

The imaginary lines of magnetic field around a magnet are called magnetic field line.



When iron fillings are allowed to settle around a bar magnet, they get arranged in a pattern which mimics the magnetic field lines.

Field lines of a magnet can also detected using a compass.

Direction of magnetic field lines

Outside the magnet, the direction of magnetic field line is taken from North Pole to South Pole. Inside the magnetic field line is taken from South Pole to North Pole.

Strength of magnetic field lines

The closeness of field lines shows the relative strength of magnetic field i.e., closer lines show stronger magnetic field and vice – versa.

Crowded field lines near the poles of magnet show more strength.

Properties of Magnetic field lines

1. Outside the magnet, the field lines run from North Pole to South Pole and inside it, these run from South Pole to North Pole. They form continuous loops.
2. Tangent to magnetic field line at a given point specifies the direction of the net magnetic field at that point.
3. Magnetic field is stronger at that point where the number of field lines per unit area is greater.
4. Two field lines can never be intersect.

Electricity and magnetism

A magnetic needle is also affected by a magnet and hence a current carrying conductor has a magnetic field around it.

Oersted's experiment

The needle deflection was always in the direction of a tangent to a circle drawn with the current carrying wire in the center and the wire being perpendicular to the plane of circle. When the direction of current in the wire was reversed, the deflection in the needle was also get reversed.

Also, the deflection increased when
(a) The current get higher

(b) The compass brought closer to the current carrying wire.

Oersted experiment Conclusion

Oersted concluded that **“current (charges in motion) creates magnetic field around it”.** He established that there is a magnetic field around a current carrying conductor.

Electric field VS magnetic field

“A charge in motion generates magnetic field just like a charge at rest generates an electric field.”

- Magnetic field at a point r is denoted by B or B(r).
- It is a vector quantity.
- S.I. unit of mag. field is Tesla (T).
- Magnetic field can change with both distance and time.

Biot – Savart’s law

The net magnetic field due to any current carrying conductor is **“the vector sum of the contributions due to the current in each infinitesimal element of length Δl**”.

$$\boxed{|dB| \propto \frac{I\Delta l \sin\theta}{r^2}}$$

$$\Rightarrow |dB| = \frac{\mu_0}{4\pi}\frac{I\Delta l \sin\theta}{r^2}$$

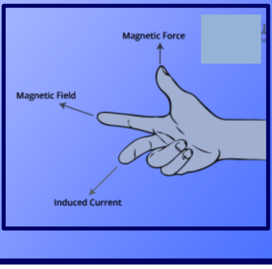
Where $\frac{\mu_0}{4\pi}$ is the constant of proportionality.

The direction of magnetic field is determined by Right hand thumb rule.

Right hand thumb rule

Imagine you are holding a current carrying straight conductor in your right hand such that the thumb is pointing towards the direction of current.

Then the fingers wrapped around the conductor give the direction of magnetic field.



Magnetic field at the center of a circular coil carrying conductor

$$\Rightarrow \quad B = \sum|AB|$$

$$\Rightarrow \quad B = \frac{\mu_0 I}{4\pi r^2}\sum \Delta l$$

$$\Rightarrow \quad B = \frac{\mu_0 I}{4\pi r^2} . 2\pi r$$

$$\Rightarrow \quad \boxed{\mathbf{B = \frac{\mu_0}{2r} I}}$$

In case there is more than one loop of wire (n turns), the field is given by:

$$\boxed{\mathbf{B = \frac{\mu_0 n I}{2r}}}$$

19

Electromagnetic induction and alternating current

Short summary

What do we learn

Quick Revision

➢ *Electromagnetic induction*

"The phenomenon in which electric current is generated by varying magnetic field is called Electromagnetic induction."

Electromagnetic induction =
Electricity + Magnetism + Induction

Induction: To induce or generate something.

Electromagnetic induction:
Induction of electric current due to magnetic field.

➢ *Faraday's experiment*

In **1831**, '**Michael faraday'** was the first who found that **current can be generated by magnetic field**.

Faraday experimented three times to study more on this electromagnetic induction.

Observations:

- Relative motion is not an absolute requirement for inducing current.
- There was induced current only when there is change in the system.

➢ *Magnetic flux*

Magnetic flux: The product of the average magnetic field times the perpendicular area it penetrates.

Mathematically, $\phi_B = \vec{B}.\vec{A}$

$\Rightarrow$ $\phi_B = \vec{B}\,\vec{A}\cos\theta$

Where A is area vector and B is the magnetic field vector.

- ϕ_B is a scalar quantity.
- Dimensional formula of magnetic flux is $[M^1L^2T^{-2}A^{-1}]$.
- SI unit of magnetic flux is Weber.
- We can define the magnetic flux $d\phi_B$ for the area element **ds** as

$$d\phi_B = B.ds$$

➢ *Faraday's law*

The quantitative description of the electromagnetic induction is known as 'Faraday's law of electromagnetic induction'.

Whenever the ϕ_B linked with closed circuit changes, an induced EMF (hence a current) is induced in it which lasts long as the change in ϕ_B. This phenomenon is known as EMI.

➢ Faraday's law

This law states that **"The magnitude of the induced current is equal to the rate of change of magnetic flux linked with the closed circuit".**

$$|\varepsilon| = \frac{d\phi_B}{dt}$$

Where ε = magnitude of induced EMF.

The total induced EMF for a coil with N turns is given by

$$|\varepsilon_r| = N\,|\varepsilon| = N\left(\frac{d\phi_B}{dt}\right)$$

➢ Lenz's law of electromagnetic induction

According to Lenz's law –:

"When a current is induced in a conductor, the direction of the current will be such that its magnetic effect opposes the change that induced it."

- It follows the law of conservation of energy.

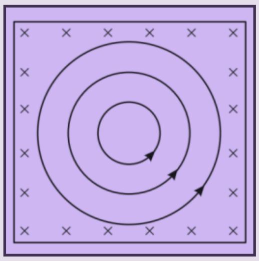
Faraday's law: $|\varepsilon| = \frac{d\phi_B}{dt}$

Lenz's law: opposition = (-ve) sign

Overall, lenz's law: $|\varepsilon| = -\frac{d\phi_B}{dt}$

➢ Eddy current

Eddy current are the current induced in solid metallic masses when the magnetic flux changing through that.



- They are circular and point in the anticlockwise direction.
- They generated in conductors.
- They follow Lenz's law for the direction.

Induced EMF can appear in these circuits in two ways:

(i) Mutual inductance

(ii) Self inductance

➢ Mutual inductance

Mutual inductance is simply the generation of an induced EMF in a coil as a result of current flowing in an adjacent coil.

➢ Self inductance

In mutual inductance, changes in the flow of current in a coil are opposed by the coil itself by inducing an EMF in the same coil, i.e., no other coil is involved.

"Self inductance is the phenomenon of production of induced EMF in a coil when a changing current passes through it."

➢ Coefficient of self inductance

The total magnetic flux linking the loop is:

$$d\phi = B.\,ds$$

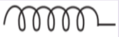
According to Biot-Savart's law: $\phi \propto I$

$$\Rightarrow \emptyset = L\,I$$

$$\Rightarrow \boxed{L = \frac{\emptyset}{I}}$$

Where L is called self-inductance of the coil.

NOTE: I is the current which is flowing, it is not induced current.

- Inductance's S.I. unit is Henry (H).
- Symbol is 

∗ Faraday's law in terms of self inductance: $\boxed{\varepsilon = -L\,\frac{I_2 - I_1}{t}}$

∗ Self inductance of solenoid is:

$$\boxed{L = \frac{\emptyset}{I} = \frac{\mu_0 N^2 A}{l}}$$

➢ LR Circuit

A circuit that containing resistance and inductance in series, is called an LR Circuit.

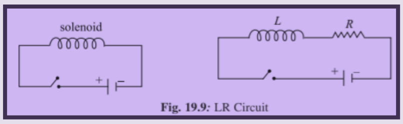


Fig. 19.9: LR Circuit

LR circuit = Inductor – Resistance circuit

➢ Mutual inductance

"Mutual inductance is the phenomenon of production of induced EMF in one coil due to a change of current in the neighboring coil."

➢ Coefficient of self inductance

$$\boxed{M = \frac{\emptyset}{I}}$$

Where M is called mutual inductance of the coil.

∗ Faraday's law in terms of self inductance: $\boxed{\varepsilon = -M\,\frac{I_2 - I_1}{dt}}$

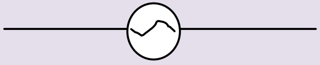
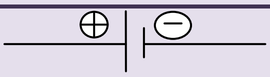
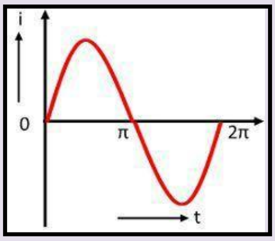
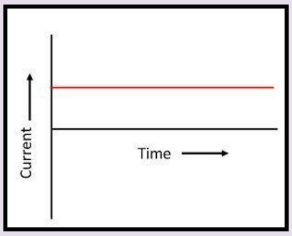
∗ Current are of two types:

① Alternating current

② Direct current

Alternating current or AC current is that current "**whose magnitude changes continuously with time and direction reverses periodically**".

To make understand easily about AC and DC, A Difference table of AC and DC is given on the next page –:

AC current	**DC current**
1. It is continuously changes with respect to time.	1. It remains constant with respect to time.
2. It shows only heating effect. $$H = I^2RT$$	2. It shows heating /chemical/ magnetic effect.
3. symbol: 	3. symbol: 
4. 	4. 

➢ *Alternating voltage and current*

$$\boxed{V = V_m \cos \omega t}$$

$$\boxed{I = I_m \cos \omega t}$$

V_m & I_m are the peak values.

*** Root mean values (rms) of V and I:**

$$\boxed{V_{rms} = \frac{V_m}{\sqrt{2}} = 0.707\ V_m}$$

$$\boxed{I_{rms} = \frac{I_m}{\sqrt{2}} = 0.707\ I_m}$$

AC current contains:

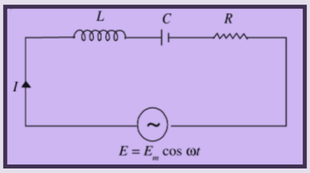
①A resistor

②A capacitor

③ An inductor

➢ *Series LCR circuit*

The current through all the three circuit elements is the same in amplitude and phase but potential differences across each of them are not in the same phase.



Phase difference: $\boxed{V_L - V_C}$

Impedence: The opposition to flow of current offered by a LCR circuit is called its impedance.

$$Z = \frac{E_{rms}}{I_{rms}} = \frac{E_0}{I_0} = \sqrt{(X_L - X_C)^2 + R^2}$$

$$= \sqrt{\left(2\pi\nu L - \frac{1}{2\pi\nu C}\right)^2 + R^2}$$

➢ *Resonance*

- Resonance is a phenomenon that occurs when the matching vibrations of another system increase the amplitude of a given system's oscillations.
- Inductive reactance (X_L) increases and capacitive reactance (X_C) decreases with increase in frequency of the applied ac source. Moreover, these are out of phase.
- Therefore, there is a certain frequency v_r for which $X_L = X_C$.

This frequency is called **resonance frequency** and at this frequency, impedance has minimum value.

$Z_{min} = R_0$

➢ *Power Generator*

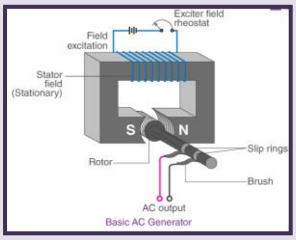
"Generator is a device that converts mechanical energy into electrical energy with the help of magnetic field."

NOTE: Generator is the most important sources of electrical power. It produces largest amount of electric power.

∗There are two types of generators:

- A.C. generator also called Alternator.
- D.C. generator also called Dynamo.

➢ *AC generator or alternator*



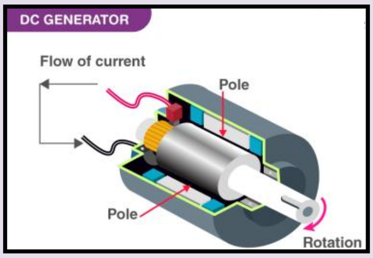
Basic AC Generator

- AC generators work on the principle of Faraday's law of electromagnetic induction.
- The various parts of an AC generator are: Field, Armature, Prime Mover, Rotor, Stator, Slip Rings

NOTE: The direction of the induced current can be identified using **Fleming's Right-Hand Rule.**

➢ *DC generator or Dynamo*

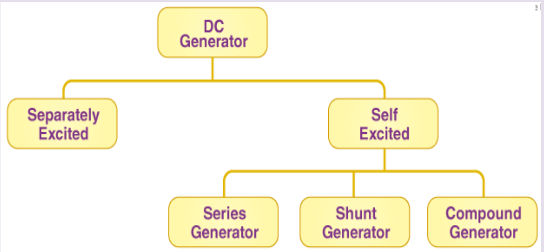
A dynamo is a machine in which **"mechanical energy is changed into electrical energy in the form of direct current"**.



- The essential parts of dynamo are: Field magnet, Armature, Commutator split rings, Brushes.

NOTE: Armatures and field magnets differ in dynamo and alternator.

➢ Types of DC generator

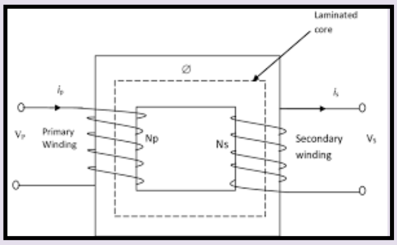

DC Generator
Separately Excited
Self Excited
Series Generator
Shunt Generator
Compound Generator

Separately excited: In this, the field coils are energized by a separate DC source.

Self excited: In this, current flowing through the field winding is supplied by the machine itself.

➢ Transformer

"A transformer is a device which transfers electric energy (or power) from primary windings to secondary windings."


Laminated core
Ø
i_p
i_s
V_p
Primary Winding
Np
Ns
Secondary winding
V_s

- Invented by **Michael Faraday** in the year 1831.
- The transformer works on the basic principles of Electromagnetic induction and mutual induction.
- A transformer consists of primary coil, secondary coil and soft core iron.

➢ Types of transformer

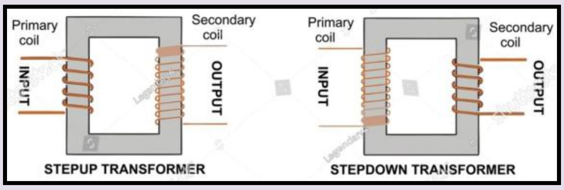
There are two types of transformers which are as follows –:

(a) Step – up transformer:

- It increases the voltage (decreases the current) in secondary windings.
- In such transformers the number of turns in secondary is more than the number of turns in primary.

(b) Step – down transformer:

- It decreases the voltage (increases the current) in the secondary windings.
- In such transformers, the number of turns in secondary is less than the number of turns in the primary.


Primary coil
INPUT
Secondary coil
OUTPUT
STEPUP TRANSFORMER
Primary coil
INPUT
Secondary coil
OUTPUT
STEPDOWN TRANSFORMER

➢ Efficiency o transformer

"Comparing system output with input will confirm transformer efficiency. The system is called better when its efficiency is high."

$$\text{Efficiency } (\eta) = \frac{\text{energy output}}{\text{energy input}} \times 100\ \%$$

$$\boxed{\eta = \frac{\textbf{Power output}}{\textbf{Power input}} \times 100\ \%}$$

NOTE: The efficiency of a transformer is less than **100%**.

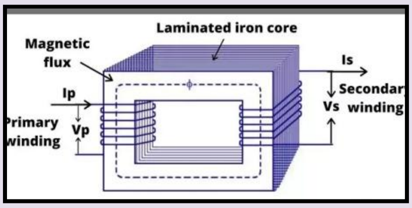
➢ How to reduce eddy currents lose?

To reduce eddy currents lose the core is formed by combining several insulated or laminated metal plates.

➢ Laminated core

A core for a transformer or other electrical machine in which the ferromagnetic alloy is made into thin sheets (laminations), which are oxidized or varnished to provide a relatively high resistance between them.

This has the effect of reducing eddy currents, which occur when alternating currents are used



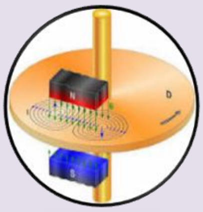
➢ Applications of eddy current

Eddy currents are used in –:

- In the brakes of train
- Electromagnetic damping
- Electric power meters
- Induction furnace

① In the brakes of train

In one basic design for an eddy current brake, a non-ferromagnetic conductive disc rotates perpendicularly through a toroidal magnetic field.



As the disc rotates, it induces eddy currents. Power is then dissipated throughout the disk to produce a braking torque force.

② Electromagnetic damping

Eddy currents create electromagnetic force and heat. The heat produced by Eddy current is used in heating the induction.

Electromagnetic forces are used in the levitation of electromagnetic trains and breaking effects.

③ Electric power meter

Eddy currents cause the shiny metal disc in the electric power metre (analogue type) to rotate.

Magnetic fields produced by sinusoidally varying currents in a coil induce electric currents in the disc.

Question – Answers

① MCQs

1. Which of the following factors is the induced charge in an electromagnetic induction independent of?

(A) Time	(B) Resistance of the coil
(C) Change of flux	(D) None of the above

Answer: (A) Time

2. A coil is placed near a changing magnetic field. Which of the following factors will NOT affect the magnitude of the induced EMF?

(A) The number of turns in the coil.
(B) The speed at which the magnetic field changes.
(C) The resistance of the coil.
(D) The orientation of the coil with respect to the magnetic field.

Answer: (C) The resistance of the coil.

3. A solenoid is connected to a battery, and a magnetic field is rapidly switched on and off within the solenoid. What will happen to the induced current if the number of turns in the solenoid is increased?

(A) The induced current increases.
(B) The induced current decreases.
(C) The induced current remains the same.
(D) The induced current becomes erratic.

Answer: (A) The induced current increases.

4. What is the unit of magnetic flux in Faraday's law?

(A) Weber (Wb)	(B) Tesla (T)
(C) Henry (H)	(D) Coulomb (C)

Answer: (A) Weber (Wb).

5. In Faraday's experiment, if the coil is replaced with a solenoid, what happens to the induced current?

(A) It increases (B) It decreases.
(C) It remains the same (D) It becomes intermittent.

Answer: (A) It increases.

6. Faraday's law is based on the principle of conservation of:

(A) Charge (B) Energy
(C) Momentum (D) Mass

Answer: (B) Energy.

7. According to Lenz's law, the direction of the induced current in a coil is such that it:

(A) Supports the change in magnetic field.
(B) Opposes the change in magnetic field.
(C) Depends on the resistance of the coil.
(D) Remains constant regardless of the change.

Answer: (B) Opposes the change in magnetic field.

8. Which of the following states that an emf is induced whenever there is a change in the magnetic field linked with electric circuits?

(A) Lenz's Law
(B) Ohm's Law
(C) Faraday's Law of Electromagnetic Induction
(D) None of the above

Answer: (C) Faraday's Law of Electromagnetic Induction

9. Which of the following gives the polarity of the induced emf?

(A) Biot – Savart Law (B) Lenz's Law
(C) Ampere's circuital Law (D) Fleming's right-hand Rule

Answer: (B) Lenz's Law

10. Electrical Inertia is the measure of:

(A) Self Inductance (B) Mutual Inductance
(C) Impedance (D) None of the above

Answer: **(A) Self Inductance**

11. **When a coil is moved into a region of a stronger magnetic field, what is the direction of the induced current according to Lenz's law?**

(A) Clockwise. (B) Counterclockwise.

(C) Depends on the speed of the motion.

(D) Opposite to the direction of motion.

Answer: **(B) Counterclockwise.**

12. **Eddy currents are induced in a conductor when:**

(A) The conductor is stationary.

(B) The conductor is in a constant magnetic field.

(C) The magnetic field around the conductor changes.

(D) The conductor is made of a superconductor.

Answer: **(C) The magnetic field around the conductor changes.**

13. **In which of the following materials are eddy currents most likely to be minimized?**

(A) Copper (B) Aluminum (C) Iron (D) Plastic

Answer: **(D) Plastic**

14. **Eddy current losses are more prominent in:**

(A) DC circuits (B) AC circuits (C) Superconductors (D) Insulators

Answer: **(B) AC circuits**

15. **Eddy currents do not cause ……………**

(A) Sparking (B) Heating (C) Loss of energy (D) Damping

Answer: **(A) Sparking**

16. **In which of the following devices, the eddy current effect is not used?**

(A) Electric heater

(B) Induction furnace

(C) Magnetic braking in train

(D) Electromagnet

Answer: **(A) Electric heater** **[PYQ NEET 2019]**

17. **What is the relationship between mutual inductance (M) and self-inductance (L) in a transformer?**

(A) M = L (B) M > L

(C) M < L (D) M is independent of L

Answer: **(A) M = L**

18. **A current of 2.5 A flows through a coil of inductance 5H. the magnetic flux linked with the coil is:** **[PYQ NEET]**

(A) 0.5 Wb (B) 12.5 Wb (C) Zero (D) 2 Wb

Answer: **(B) 12.5 Wb**

19. **If a step-up transformer has a turns ratio of 1:3, and the primary voltage is 120V, what is the secondary voltage**?

(A) 40V (B) 120V (C) 180V (D) 360V

Answer: **(D) 360V**

20. **Which of the following apparatus construction uses electromagnetic induction?**

(A) Voltmeter (B) Galvanometer

(C) Generator (D) Electric Motor

Answer: **(C) Generator**

21. **To manufacture the core of transformer, the best material is:**

(A) Stainless steel (B) Hard steel

(C) Soft iron (D) Mild steel

Answer: **(C) Soft iron**

22. **Which of the following factors is the self inductance associated with a coil is independent of?**

(A) Induced voltage (B) current

(C) Time (D) Coil resistance

Answer: **(D) Coil resistance**

23. Which of the following rules is used to identify the direction of the current induced in a wire moving in a magnetic field?

(A) Ampere’s Rule
(B) Fleming’s Left-Hand Rule
(C) Fleming’s Right-Hand Rule
(D) None of the above

Answer: **(B) Fleming’s Left-Hand Rule**

24. A metal ring is held horizontally and bar magnet is dropped through the ring with its length along the axis of the ring. The acceleration of the falling magnet is: **[PYQ – NEET 1996]**

(A) More than g (B) equal to g
(C) Less than g (D) either (a) or (c)

Answer: **(C) Less than g**

25. Current passing through a coil of 5 H decreases at the rate of 2 A/sec. this develops an emf across the coil which is equal to

(A) -10 V (B) 10 V (C) -2.5 V (D) 2.5 V

Answer: **(B) 10 V**

② Complete the sentence using an appropriate words:

26. Complete the sentence by using an appropriate word given below –:

Weber, doubled, another nearby coil, magnetic flux, changing

(a) If the number of turns in a coil is doubled, the induced EMF is ………………

(b) Faraday's experiments demonstrated that a magnetic field can induce an EMF only when it is **…………..**

(c) According to Lenz's law, the direction of the induced current is such that it opposes the change in …………… that produced it.

(d) Mutual induction occurs when a change in magnetic flux in one coil induces an EMF in ……………..

(e) The unit of magnetic flux is ……………..

Answer: **(a) doubled, (b) changing, (c) magnetic flux, (d) another nearby coil, (e) Weber**

③ Fill in the blanks:

27.

1. In electromagnetic induction, line integral of induced field E around a closed path is ……………, induced electric field is ……………

2. The efficiency of a transformer is less than ……………

3. Transformers are invented by ……………

4. Generator is a device which converts mechanical energy into ……………

5. DC …………… with respect to time.

Answer: **(1) zero, non – conservative, (2) 100%, (3) Michael Faraday, (4) electrical energy (5) remains constant**

④ Match the following:

28. **Match the statement given in column A with the right option given in column B:**

COLUMN A	COLUMN B
1. Faraday's law	(a) Henry
2. Unit of inductance	(b) $\oint \vec{E} . d\vec{l}$
3. Lenz's law	(c) Volt
4. Unit of Impedance in AC Circuit	(d) $-N\frac{d\emptyset}{dt}$

Answer: **(1) – (d), 2 – (a), 3 – (b), 4 – (c)**

⑤ True or False:

29. The induced emf is equal to the coefficient of self-inductance is equal to unity, when the rate of change of current is unity.

⇒ True.

30. A transformer can only work with DC (direct current) input.

⇒ False.

31. Faraday's law states that the induced electromotive force (emf) in a coil is directly proportional to the rate of change of magnetic flux through the coil.

⇒ True.

32. Lenz's law suggests that the direction of the induced current in a coil is such that it opposes the change in magnetic flux that produced it.

⇒ True.

33. Inductive reactance in an AC circuit is inversely proportional to the inductance (L).

⇒ False.

34. The unit of mutual inductance (M) is Henry (H).

⇒ True.

35. Power factor is the ratio of the real power (W) to the apparent power (S) in an AC circuit.

⇒ True.

36. Transformers can only step up the voltage; they cannot step it down.

⇒ False.

37. A transformer with a turns ratio greater than 1 is not a step-up transformer.

⇒ False.

38. Quality factor (Q) is a measure of the sharpness of resonance in an RLC circuit.

⇒ True.

39. Magnetic flux in a transformer core is directly proportional to the applied voltage.

⇒ False.

⑥Very short type question [2 marks of each]:

40. Define the term 'self-inductance' of a coil. Write its S.I. Unit.

Answer: The self inductance of a coil numerically equals to the induced emf produced in the coil, when rate of change of current in coil is unity.

$$\varepsilon = -L\frac{dI}{dt}$$

Where L is the self inductance of the coil.
S.I. Unit of self inductance is Henry.

41. Name any four applications where eddy currents are used to advantage.

Answer: Applications of Eddy currents are as:

(1) Electromagnetic Damping
(2) Magnetic Breaking
(3) Induction Furnace
(4) Electric Power metres

42. What are the values of the capacitive and inductive reactance in a dc circuit.

Answer: $X_C = \infty$ for $dc_v = 0 X_C = \frac{1}{\omega_c} = \frac{1}{2\pi vc} = \infty$

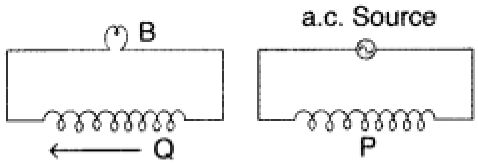
$X_L = 0$ & $X_L = \omega L = 2\pi v L = 0$

43. Define RMS value of current.

Answer: RMS value of ac is defined as that value of direct current which produce the same heating effect in a given resistor as is produed by the given alternating current when passed for the same time.

$$I_{rms} = \frac{I_0}{\sqrt{2}} = 0.707\ I_0$$

44. **A coil Q is connected to low voltage bulb B and placed near another coil P as shown in the figure. Give reasons to explain the following observations :**



(a) The bulb 'B' lights.

(b) Bulb gets dimmer if the coil Q is moved towards left.

Answer: The bulb B lights on account of emf induced in the coil Q due to mutual induction between P and Q.

When coil Q is moved towards left, magnetic flux linked with Q decreases and may even reduce to zero at some distance. The emf induced may decrease and the bulb B gets dimmer.

45. **Two identical loops, one of copper and the other of aluminium, are rotated with the same angular speed in the same magnetic field. Compare**
(i) the induced emf and
(ii) the current produced in the two coils. Justify your answer.

Answer: (i) Induced emf in a coil is $\varepsilon = NBA\omega \sin \omega t$

As the angular speed is same, induced emf will also be same in both the loops.

(ii) Current induced in a loop is $I = \frac{\varepsilon}{R} = \frac{\varepsilon A}{\rho l}$

As the resistivity of copper is lesser, more amount of current is induced in it.

46. **State Lenz's Law. A metallic rod held horizontally along east-west direction, is allowed to fall under gravity. Will there be an emf induced at its ends? Justify your answer.**

Answer: Lenz's law states that "the polarity of induced emf is such that it tends to produce a current, which oppose the change in magnetic flux that induced it".

Yes there will be an emf induced as the horizontal component of field of earth, velocity of the motion of the rod and the length of the rod are all perpendicular to each other. The magnetic flux due to vertical component of Earth's magnetic field keeps on changing as the metallic rod falls down.

47. Can you increase the energy stored in an inductor by 4 times?

Answer: Let initially, the energy stored in an inductor is, $E_i = 1/2\ LI_i^2$

The final energy stored in the inductor is, $E_f = 1/2\ LI_f^2$

When the energy stored in the inductor becomes 4 times the initial value i.e.

$$E_f = 4E_i,$$

$$\Rightarrow E_f = 4E_i = 1/2\ LI_f^2$$

$$\Rightarrow 4 \times 1/2\ LI_i^2 = 1/2\ LI_f^2$$

$$\Rightarrow I_f = 2I_i$$

Hence when the current is doubled, the energy stored in the inductor becomes 4 times.

48. What are the factors on which self inductance depends?

Answer: $L = \frac{\mu_0 N^2 A}{l}$

It depends on number of turns N, area of cross section A and permeability of core material μ_0.

49. Name the methods of generating induced emf?

Answer: The methods of generating induced emf are as follows –:

- Induced EMF by changing the magnetic field B
- Induced EMF by changing the area of coil
- Induced EMF by changing the relative orientation of the coil and the magnetic field.

50. When the current changes from +2A to – 2A in 0.05s, an EMF of 8V is induced in the coil. The coefficient of self induction of coil is?

Answer: Given: L = 8v

E = | L dI/dT |

⇒ E = (8 V × 0.05) /4

⇒ E = 0.1 H

51. Two coils of self inductance 2mH and 8mH are placed so close together that the effective flux in one coil is completely linked with the other. The mutual inductance between these coil is?

Answer: Given: L_1 = 2 mH, L_2 = 8 mH

$$M = \sqrt{(L_1 \times L_2)}$$

$$M = \sqrt{2 \times 8}$$

M = 4 mH

52. In EMI, why is the induced emf not dependent on the résistance of the coil?

Answer: E = – dØ/dt

dØ = change of flux = NBA cosθ ,
dt = change of time , N = number of turns, B = Magnetic energy

According to above equation it seems that it is independent of resistance of coil.

53. The same magnetic field rotates two similar loops made of copper and aluminum at the same angular speed. Compare the following.
(i) The induced emf
(ii) The current that the two coils produce

Answer: (i) The induced emf in a coil is = NBA sin t. Due to the identical angular speed in both loops, the induced emf will likewise be the same.

(ii) The current that will be induced in a loop is I = R = Apl. More current is induced in copper because its resistance is lower.

54. A coil having 100 turns and area of 0.001 metre2 is free to rotate about an axis. The coil is placed perpendicular to magnetic field of 1.0.weber/metre^2. If the coil is rotate rapidly through an angle of 180°, how much charge will How through the coil? The resistance of the coil is 10 ohm.

Answer: The flux linked with the coil when the plane of the coil is perpendicular to the magnetic field is Ø = nABcos θ = nAB

The change in flux on rotating the coil by 180° is dØ = Nab – (– nAB) = 2nAB

$$\therefore \text{induced charge} = \frac{d\emptyset}{dr} = \frac{2nAB}{dt} = \frac{2 \times 100 \times 0.001 \times 1}{10} = 0.01\ C$$

⑦Short type question [3 marks of each]:

55. A L inductor of XL reactance is linked in series with a bulb B to an a.c. source as illustrated in the figure. Briefly explain the process of the brightness of the bulb changing when

(a) The number of turns of the inductor is reduced.

(b) A capacitor of reactance XC = XL is inclusive within a series in the same circuit.

Answer:

(a) We know, Z = $R_2 + XL_2$

When the number of turns of the inductor gets lessened XL and Z reduces and gradually increases. Because of this, the bulb would glow more brightly.

(b) When the capacitor is inclusive within the circuit, Z = $R_2 + XL - XC_2$ But, provided that, XC = XL That implies at minimum, Z= R

Hence, the bulb's brightness will turn into maximum.

56. A horizontal straight cable 10m long expanding from east to west is falling with a speed of 5.0ms^{-1}, at particular angles to the horizontal component of the magnetic field of the Earth 0.30 × 10^{-4} Wbm^{-2}.

(a) What is the immediate value of the emf induced in the cable?

(b) What is the emf's direction?

(c) Which of the wire's ends is at the higher electrical potential?

Answer: **(a)** Given that, the wire's length, l = 10m

The wire's falling speed, v = 5.0m / s,

Magnetic field strength, $B = 0.3 \times 10^{-4} \text{Wbm}^{-2}$

Emf induced in the wire, $\varepsilon = B\, l\, v$

$$\varepsilon = 0.3 \times 10^{-4} \times 10 \times 5$$

$$\varepsilon = 1.5 \times 10^{-3} \text{V}$$

(b) The direction of the emf induced is from West to East as of Fleming's right-hand rule.

(c) The wire's eastern end is at higher potential.

57. **Answer the following questions.**

(i) The galvanometer exhibits brief deflection when primary coil P is shifted in the direction of secondary coil S (as shown in the figure). What may be done to increase the galvanometer's deflection while using the same battery?

(ii) Also mention the related law.

Answer: (i) Coil P must be brought closer to coil S more quickly so that the rate of change of magnetic flux is greater in order to have a larger deflection in the galvanometer with the same battery.

(ii) Faraday's second law of electromagnetic induction, which states that induced emf is created in a circuit when magnetic flux associated with it changes, is the related law guiding this occurrence. The rate of change of magnetic flux has a direct relationship with the strength of the induced emf.

58. **What do you mean by eddy currents? Mention any two use cases of eddy current.**

Answer: Eddy currents are created when there is an induced current in the volume (or bulk) of a material as a result of a change in magnetic flux. It can be utilised in devices like electric brakes, induction furnaces, deadbeat galvanometers, and more, and it results in energy loss while producing heat, making it a necessary evil in an arrangement.

They are useful in induction heating, levitating, electromagnetic damping, and electromagnetic braking.

59. Distinguish between resistances, reactance and impedance of an a.c. circuit?

Answer:

	Resistance	**Reactance**	**Impedance**
1	Opposition offered by the resistor to the flow of current	Opposition offered by the inductor or capacitor to the flow of current	Opposition offered by the combination of resistor, inductor or capacitor
2	It is independent of the frequency of the source.	It depends on the frequency of the source	It depends on the frequency of the source

⑧Long type answer question (4 marks of each)

60. Define self inductance and write the S.I unit of a coil's self-inductance. Derive an expression for self inductance of a long solenoid of length l, cross-sectional area A having N number of turns.

Answer: The magnetic flux that is linked with the coil and the current passing through it at a given instance will be directly proportional to each other. $\emptyset \propto I$

$\Rightarrow \quad \emptyset = LI$, Here, L refers to the coefficient of self-induction.

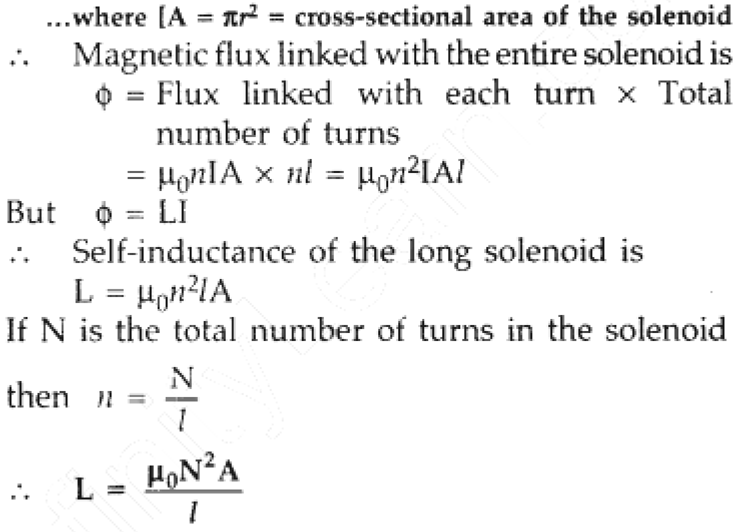
If $I = 1$, then $\emptyset = L$

Hence, when a unit current passes through a coil, its self-inductance is numerically equal to the magnetic flux associated with the coil.

Henry is the SI unit (H) of self-inductance.

Consider a long solenoid of length l and radius r with r << 1 and having n turns per unit length.

If a current I flows through the coil, then the magnetic field inside the coil is almost constant and is given by: $B = \mu_0 nI$
Magnetic flux linked with each turn = $BA = \mu_0 nIA$



...where [$A = \pi r^2$ = cross-sectional area of the solenoid

∴ Magnetic flux linked with the entire solenoid is

ϕ = Flux linked with each turn × Total number of turns

$= \mu_0 nIA \times nl = \mu_0 n^2 IAl$

But $\phi = LI$

∴ Self-inductance of the long solenoid is

$L = \mu_0 n^2 lA$

If N is the total number of turns in the solenoid

then $n = \frac{N}{l}$

$$\therefore \quad L = \frac{\mu_0 N^2 A}{l}$$

61. **Inducting circular loop is placed in a uniform magnetic field B = 0.025 T with its plane perpendicular to the field. The radius of the loop is made to shrink at a constant rate 1 mm s^{-1}. The induced e.m.f. when the radius is 2 cm is?**

Answer: Given: B = 0.025 T, R = 2 cm

$dr/dt = 1 \text{ mm } s^{-1}$

The direction of B and A is same

$|E| = |-d\phi/dt|$

$E = d\varphi/dt$

$E = d(BA \cos 0°)/dt$

$E = B \cos 0° \, dA/dt$

$E = B \, d(\pi R^2)/dt$

$E = B \, 2\pi R \, dR/dt$

$E = 0.025 \times \pi \times 2 \times 2 \times 10^{-4} \times 1 \times 10^{-3}$

$E = \pi \times 10^{-6}$ V

$E = \pi$ μV

62. **(A) What is mutual induction?**

(B) A magnetic field of 2×10^{-2} T acts at right angles to a coil of area 100 cm^2 with 50 turns. The average EMF induced in the coil is 0.1v, when it is removed from the field in the time t. the value of t is?

Answer:

(A) Mutual induction: When two coils are brought in proximity with each other then the magnetic field in one of the coils tends to link with the other coil. This leads to generation of voltage in the second coil. This property of the coil that affects or changes the current and voltage in the secondary coil is called mutual inductance.

(B) Given: N = 50, $B = 2 \times 10^{-2}$ T, A = 100 cm^2, E = 0.1 v

$|E| = |-d\emptyset/dt|$

$|E| = |\emptyset_2 - \emptyset_1/dt|$

$dt = |0 - NBA \cos 0° / 0.1|$

[0˚ because it acts as a right angle of a coil]

$dt = |0 - 50 \times 2 \times 10^{-2} \times 100 \times 10^{-4} \cos 0 / 0.1|$

dt = 0.1 s

63.

(A) State Faraday's laws of electromagnetic induction. [PYQ NIOS Oct. 2022]

(B) What are Eddy currents? Give one advantage and disadvantage of Eddy currents.

(C) Give the method to reduce Eddy currents in the electrical appliance.

Answer:

(a) Faraday's Law: It states that the induced electromotive force (EMF) in any closed circuit is equal to the rate of change of magnetic flux through the circuit.

Mathematically, it can be expressed as: EMF = $\frac{d\phi_B}{dt}$

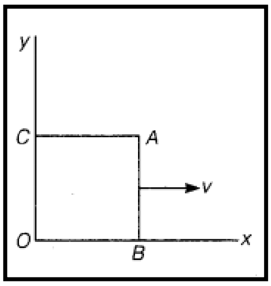
(b) Eddy Currents: Eddy currents are circulating currents induced in a conductor when it is exposed to a changing magnetic field. These currents circulate within the conductor in closed loops and result in localized circulating currents.

‘Advantage’ of eddy current is these are used for induction heating in applications such as cooking appliances and induction furnaces.

‘Disadvantage’ of eddy current is that eddy currents lead to energy dissipation in the form of heat. This can result in energy loss and reduced efficiency in electrical devices.

(c) To reduce eddy currents in electrical appliances, especially in devices like transformers and electric motors, ‘laminating the core’ is a common technique. This involves dividing the magnetic core into thin laminations separated by insulating layers.

64. A magnetic field $B = B_0 \sin(\omega t)\,\hat{k}$ covers a large region where a wire AB slides smoothly over two parallel conductors separated by a distance d (figure). The wires are in the x-y plane. The wire AB (of length d) has resistance R and the parallel wires have negligible resistance. If AB is moving with velocity y, what is the current in the circuit. What is the force needed to keep the wire moving at constant velocity?



Answer:

Let us assume that the parallel wires are at y = 0 i. e., along x-axis and y = d.

At t = 0, AB has x = 0, i. e., along y-axis and moves with a velocity v. Let at time t, wire is at x (t) = vt.

Now, the motional emf across AB is = $(B_0 \sin\omega t)\, vd(-\hat{j})$
emf due to change in field (along OBAC) = $-B_0\omega\cos\omega t\,(t)d$

Total emf in the circuit = emf due to change in field (along OBAC) + the motional emf across AB = $-B_0d[\omega x\cos(\omega t) + v\sin(\omega t)]$
Electric current in clockwise direction is given by, = $B_0dR = (\omega x\cos\omega t + v\sin\omega t)$
The force acting on the conductor is given by $F = ilB\sin 90° = ilB$

we have Force needed along i = $\frac{B_0 d}{R}(\omega x\cos\omega t + v\sin\omega t) \times d \times B\sin\omega t$

= $\frac{B_0^2 d^2}{R}(\omega x\cos\omega t + v\sin\omega t)\sin\omega t$
This is the required expression for force.

⑨Very long type answer question (5 marks of each)

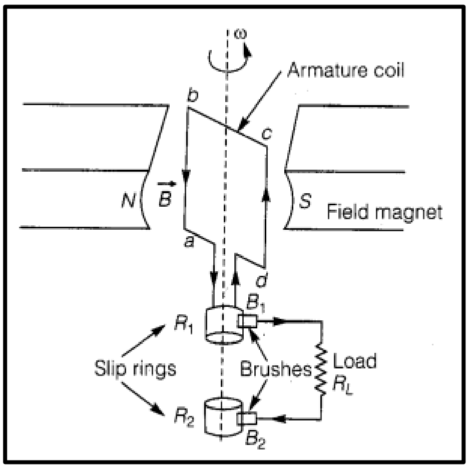
65. State the working of AC generator with the help of a labelled diagram. The coil of an AC generator having N turns, each of area A, is rotated with a constant angular velocity to. Deduce the expression for the alternating emf generated in the coil. What is the source of energy generation in this device?

Answer:

AC Generator: A dynamo or generator is a device which converts mechanical energy into electrical energy.

Principle: It works on the principle of electromagnetic induction. When a coil rotates continuously in a magnetic field, the effective area of the coil linked normally with the magnetic field lines, changes continuously with time. This variation of magnetic flux with time results in the production of an alternating emf in the coil.

Construction: It consists of the four main parts



- Field magnet: It produces the magnetic field. In the case of a low power dynamo, the magnetic field is generated by a permanent magnet, while in the case of large power dynamo, the magnetic field is produced by an electromagnet.

- Armature: It consists of a large number of turns of insulated wire in the soft iron drum or ring. It can revolve an axle between the two poles of the field magnet. The drum or ring serves the two purposes: (a) It serves as a support to coils and (b) It increases the magnetic field due to air core being replaced by an iron core.

- Slip rings: The slip rings R_1 and R_2 are the two metal rings to which the ends of armature coil are connected. These rings are fixed to the shaft which rotates the armature coil so that the rings also rotate along with the armature.

- Brushes: There are two flexible metal plates or carbon rods (B_1 and B_2) which are fixed and constantly touch the revolving rings. The output current in external load RL is taken through these brushes.

Working: When the armature coil is rotated in the strong magnetic field, the magnetic flux linked with the coil changes and the current is induced in the coil, its direction being given by Fleming's right hand rule.

Considering the armature to be in vertical position and as it rotates in anticlockwise direction, the wire ab moves upward and cd downward, so that the direction of induced current is shown in fig. In the external circuit, the current flows along $B_1R_lB_2$. The direction of current remains unchanged during the first half turn of armature. During the second half revolution, the wire ab moves downward and cd upward, so the direction of current is reversed and in external circuit it flows along $B_2R_LB_1$ Thus the direction of induced emf and current changes in the external circuit after each half revolution.

Expression for Induced emf: If N is number of turns in coil, f the frequency of rotation, A area of coil and B the magnetic induction, then induced emf:

$$e = -\frac{d\emptyset}{dt} = -\frac{d}{dt}\{\mathrm{NBA}\,(\cos 2\pi\, ft)\} = 2\pi\, \mathrm{NBA}\, f \sin 2\pi\, ft$$

Obviously, the emf produced is alternating and hence the current is also alternating.

Current produced by an AC generator cannot be measured by moving coil ammeter; because the average value of AC over full cycle is zero.

The source of energy generation is the mechanical energy of rotation of armature coil.

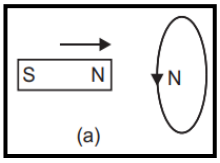
66. State Lenz's law. "The Lenz's law is a consequence of the principle of conservation of energy." Justify this statement.

(b) Deduce an expression for the mutual inductance of two long coaxial solenoids but having different radii and different number of turns.

[Given in sample paper]

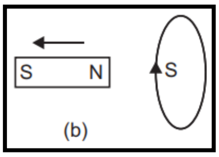
Answer: (a) Lenz's law: According to this law "the direction of induced current in a closed circuit is always such as to oppose the cause that produces it." Example: When the north pole of a coil is brought near a closed coil, the direction of current induced in the coil is such as to oppose the approach of north pole.

For this the nearer face of coil behaves as north pole. This necessitates an anticlockwise current in the coil, when seen from the magnet side [fig. (a)]



(a)

Similarly when north pole of the magnet is moved away from the coil, the direction of current in the coil will be such as to attract the magnet. For this the nearer face of coil behaves as south pole. This necessitates a clockwise current in the coil, when seen from the magnet side (fig. b).



(b)

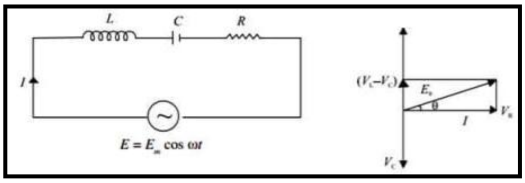
Conservation of Energy in Lenz's Law: Thus, in each case whenever there is a relative motion between a coil and the magnet, a force begins to act which opposes the relative motion. Therefore to maintain the relative motion, a mechanical work must be done. This work appears in the form of electric energy of coil. Thus Lenz's law is based on conservation of energy.

(b) Suppose two co-axial solenoids S_1 and S_2 of radii r_1 and r_2 , number of turns N_1 and N_2 each of length 'l' Suppose I1 is the current in outer solenoid; magnetic field at the axis, B_1 = m where $n_1 = \mu_0 n_1 L_1$ number of turns/meter of outer solenoid. Magnetic flux linked with inner solenoid (S_2).

67. Using phasor diagram for a series LCR circuit connected to an ac source of voltage E = Em cos ω t, derive the relation for the current flowing in the circuit and the expression for resonance frequency. Draw a plot showing the variation of the peak current (im) with frequency of the a.c. source used. **[Given in sample paper]**

Answer:

From phasor



diagram

$$\Rightarrow \mathrm{I} = \frac{V}{\sqrt{R^2+(X_C-X_L)^2}}$$

$$V = \sqrt{V_R^2 + (V_C - V_L)^2}$$
$$V = \sqrt{(IR)^2 + (IX_C - IX_L)^2}$$
$$V = I\sqrt{R^2 + (X_C - X_L)^2}$$

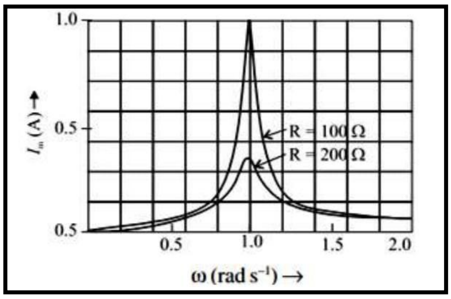
Obviously, effective resistance of the circuit, known as impedance is given by

$$Z = \sqrt{(\mathrm{R})^2 + (\mathrm{X_c} - \mathrm{X_L})^2}$$

At resonance: $\mathrm{X_L} = \mathrm{X_C}$

$$\Rightarrow \quad \omega \mathrm{L} = \frac{1}{\omega \mathrm{C}}$$

$$\Rightarrow \quad \omega^2 = \frac{1}{\sqrt{\mathrm{LC}}}$$



68. Answer the following questions:

(a) In any AC circuit, is the applied instantaneous voltage equal to the

algebraic sum of the instantaneous voltages across the series elements of the circuit? Is the same true for RMS voltage?

(b) Why a capacitor is used in the primary circuit of an induction coil?

(c) An applied voltage signal consists of a superposition of a DC voltage and an AC voltage of high frequency. The circuit consists of an inductor and a capacitor in series. Show that the DC signal will appear across C and the AC signal across L.

(d) A choke coil in series with a lamp is connected to a DC line. The lamp is seen to shine brightly. Insertion of an iron core in the choke causes no change in the lamp's brightness. Predict the corresponding observations if the connection is to an AC line.

(e) Why is choke coils needed in the use of fluorescent tubes with AC mains? Why can we not use an ordinary resistor instead of the choke coil?

Answer:

(a) Yes, the applied instantaneous voltage is equal to the algebraic sum of the instantaneous voltages across the series elements of the circuit. The same is not true for RMS voltage because voltages across different elements may not be in phase.

(b) When the circuit is broken, the high induced voltage is used to charge the capacitor, thus avoiding sparks, etc.

(c) For a DC signal, the impedance across the inductor is negligible, and the impedance of the capacitor is very high (infinite). So the DC signal appears across the capacitor. For high-frequency AC, the impedance across the inductor is high, and that of a capacitor is low. So, the AC signal appears across the inductor.

(d) For a steady state DC, L has no effect, even if it is increased by an iron core. For AC, the lamp will shine dimly because of the additional impedance of the choke. It will dim further when the iron core is inserted, which increases the choke's impedance.

(e) A choke coil reduces the voltage across the fluorescent tube without wasting power. A resistor would waste power as heat.

21

Dispersion and scattering of light

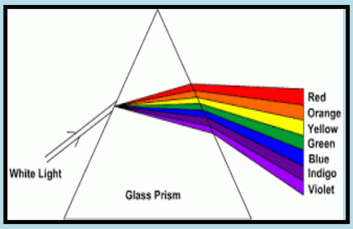
Short summary

What do we learn

Quick Revision

➢ Introduction

When a narrow beam of ordinary light is refracted by prism, we see colour bands. This phenomenon is something about dispersion.



➢ Dispersion of light

The splitting of white light into its constituent colours or wavelengths by a medium is called Dispersion.

We know that light has two nature
- **particle nature** and **wave nature**
Here, we read only about the wave nature of light.

- Light waves are the transverse electromagnetic waves and their speed **$3 \times 10^7 ms^{-1}$** in vacuum.
- Sunlight consists of seven colours: **Violet**, **Indigo**, **Blue**, **Green**, **Yellow**, **Orange**, **Red** (VIBGYOR). These colours may be identified by their wavelength.

➢ Refractive index

The ratio of speed of light in vacuum to the speed of light in the medium is termed as refractive index.

Refractive index (μ) = $\frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$

$$\boxed{\mu = \frac{v_{vac}}{v_{med}} = \frac{c}{v}}$$

“The variation of the refractive index of a material with wavelength is known as Dispersion.”

‘μ’ depends on: (1) Nature of material (2) The wavelength of light : **$\mu \propto 1/\lambda$**

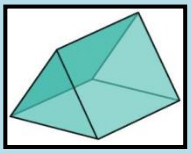
➢ Dispersive medium

In an optically denser medium, the component wavelengths (colours) travel with different speeds and therefore get separated, such a medium is called **Dispersive medium**.

➢ Non -Dispersive medium

In free space and even in air, the speeds of all waves of the visible light are the same. So, they are not separated, such a medium is called a **Non-Dispersive medium**.

➢ Dispersion through a prism



A prism has 5 faces three of them are rectangular and two are triangular faces.

- When white light is passed through prism then it split in seven colours.

- Light of single colour is called monochromatic light while of more colours is said to be polychromatic wavelength.

➢ Some important terms

Spectrum: The band of seven colors is called spectrum.

Incident ray: The ray of white light which enters in the prism is called incident ray.

Emergent ray: The ray of light of seven colours which is emerged from the prism is called emergent ray.

Deviation: The bending of the original beam along incident ray and emergent ray is known as deviation.

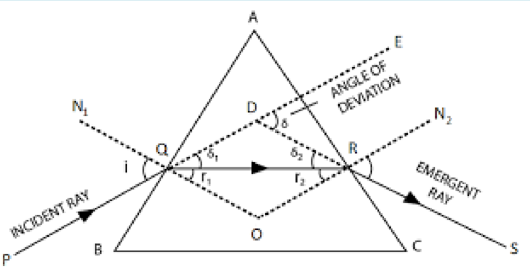
Angle of Deviation: The angle between the emergent ray and the incident ray is known as the Angle of deviation.

➢ Cause of dispersion

Different colours of white light have different speeds in the Refracting medium. So they bend through different angles inside the prism. Hence this is the cause of dispersion.

➢ Angle of deviation

"The angle between the emergent ray RS and the incident ray PQ at D is known as the angle of deviation (δ)."



∠BAC = ∠A = Angle of prism

∠NQP = ∠i = Angle of incidence

∠MRS = ∠e = Angle of emergence

∠ MDR = ∠δ = Angle of Deviation

$$\boxed{\angle A = \angle r_1 + \angle r_2}$$

$$\boxed{\angle i + \angle e = \angle A + \angle \delta}$$

➢ Angle of minimum deviation δ_m

$$\boxed{i = \frac{A+\delta_m}{2}}$$

$$\boxed{\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}}$$

$$\boxed{\delta = (\mu - 1)}$$

➢ *Why red colour deviate most and violet least?*

We know that Wavelength of red is most and wavelength of violet is least.

$$\lambda_{red} \gg \lambda_{violet}$$

Refractive index depends on the wavelength ($\mu \propto \frac{1}{\lambda}$)

$$\Rightarrow \quad \mu_{red} \ll \mu_{violet}$$

Angle of deviation depends on the refractive index. {$\delta = (\mu - 1) A$}

$$\Rightarrow \quad \boxed{\delta_{red} \ll \delta_{violet}}$$

The deviation of the red light would be less as compared to that of the violet light.

➢ *Angular dispersion*

"The difference between angle of deviation of two different colours is known as angular dispersion."

The angular dispersion between the red and violet is $\delta_{violet} - \delta_{red}$.

➢ *Dispersive power*

It is the ability of prism material to cause the dispersion.

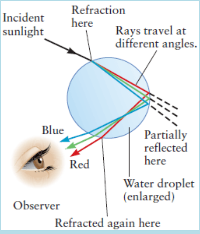
"The ratio of the angular dispersion to the mean deviation is taken as the dispersive power (ω) of the material of the prism."

$$\boxed{\omega = \frac{\mu_v - \mu_r}{\mu_{mean} - 1}} \quad \text{Or} \quad \boxed{\omega = \frac{\Delta\mu}{(\mu_{mean} - 1)}}$$

➢ *Rainbow formation*

A rainbow is a natural spectrum appearing in the sky after a rain shower.

It is caused by dispersion of sunlight by tiny water droplets, present in the atmosphere. A rainbow is always formed in a direction opposite to that of the Sun.



The water droplets act like small prisms. They refract and disperse the incident sunlight, then reflect it internally, and finally, refract it again when it comes out of the raindrop. Due to the dispersion of light and internal reflection, different colors reach the observer's eye.

➢ *Scattering of light*

It is the phenomenon in which **"light rays deviate from their original path upon striking an obstacle like dust, gas molecules, or water vapors".**

It is a two step process:
(i) Absorption of light by the scattering particle and
(ii) Instant re-emission by it in all possible directions.
Thus, this phenomenon is different from reflection.

➢ *Rayleigh's law*

According to this law, **"the intensity of scattered light is inversely proportional to the fourth power of its wavelength"**.

$$\boxed{I \propto \frac{1}{\lambda^2}}$$

Thus, when white light is incident on the scattering particle**,** the blue light is scattered the most and the red light is scattered the least.

∗ On the basis of scattering of light, we can explain

- Why sky appears blue,
- Clouds appear white
- The sun appears red at sunrise as well as at sunset.

(A) *Blue colour of sky*

Scattering of sunlight through molecules of atmosphere is the reason for the blue of the sky.

Our atmosphere contains atoms and molecules of different sizes. According to their sizes they are able to scatter different wavelength of light. It acts as scattering centre for other frequencies which are lower than the frequency of blue light.

Blue colour scatters more than other colours.

That is why sky appears blue.

(B) *White colour of clouds*

The clouds are formed by the assembly of small water drops whose size becomes more than the average wavelength of the visible light (5000Å).

These droplets scatter all the wavelengths with almost equal intensity. The resultant scattered light is therefore white. So, a thin layer of clouds appears white.

(C) *Red colour of the sun at sunset and sunrise:*

During sunrise and sunset, the rays have to travel a larger part of the atmosphere because they are very close to the horizon. Therefore, light other than red is mostly scattered away. Most of the red light, which is the least scattered, enters our eyes. Hence, the sun and the sky appear red.

➢ *Raman effect*

"When light radiation undergoes scattering from a transparent substance then the frequency of the scattered radiation may be greater or less than the frequency of the incident radiation."

This phenomenon is known as Raman effect as it was first observed by CV. Raman in 1926.

➢ *Raman spectrum*

The spectrum of the scattered radiation is known as Raman spectrum.

Anti-Stokes' lines: This spectrum has lines having frequency greater than the frequency of the incident radiation called Anti – stokes lines.

Stokes' lines: spectrum has also lines having frequency less than the frequency of the incident radiation called stokes' lines.

➢ *Possibilities of Raman effect*

When light radiation interacts with a substance three possibilities may arise which are as follows –:

❶The light radiation interacting with the substance does not undergo any change of energy. Hence, its frequency remains unchanged.

❷The light radiation may impart some of its energy to the substance. As a result, the energy of the light radiation decreases. This leads to a decrease in the frequency of the scattered radiation (corresponding to Stokes' lines).

❸The incident radiation may interact with the substance which is already in the excited state. In the process, the radiation gains energy resulting into increase in its frequency (corresponding to anti-Stokes' lines).

Question – Answer

① MCQs

1. **What is the phenomenon by which a beam of white light separates into its component colors when passing through a prism?**
   (A) Reflection (B) Refraction (C) Dispersion (D) Diffraction

Answer: (C) Dispersion

2. **When white light is incident on a glass prism, the color that deviates the least is:**
   (A) Violet (B) Red (C) Green (D) Blue

Answer: (B) Red

3. **In the context of dispersion, which property of light changes as it travels from one medium to another?**
   (A) Amplitude (B) Wavelength (C) Frequency (D) Velocity

Answer: (B) Wavelength

4. **When a narrow beam of white light passes through two prisms in series, what happens to the spectrum produced?**
   (A) It remains the same
   (B) It disappears
   (C) It gets wider
   (D) It gets narrower.

Answer: (A) It remains the same.

5. **A glass prism is immersed in a medium with a higher refractive index than that of the prism. What effect does this have on the dispersion of light?**
   (A) Decreases dispersion
   (B) Increases dispersion
   (C) No effect on dispersion
   (D) Inverts the colors in the spectrum

Answer: **(A) Decreases dispersion**

6. **The dispersion of light is more pronounced in which of the following conditions?**
   (A) Parallel beam of light
   (B) Diverging beam of light
   (C) Converging beam of light
   (D) Collimated beam of light

Answer: **(C) Converging beam of light**

7. **In the context of dispersion, which color of light experiences the maximum change in speed when passing from air to glass?**
   (A) Red (B) Blue (C) Green (D) Violet

Answer: **(B) Blue**

8. **What is the refractive index of a medium with respect to air?**
   (A) 0 (B) 1 (C) Greater than 1 (D) Less than 1

Answer: **(C) Greater than 1**

9. **Which of the following statements about the refractive index is correct?**
   (A) It is independent of the wavelength of light.
   (B) It is inversely proportional to the speed of light in the medium
   (C) It is the same for all colors of light in a given medium.
   (D) It is directly proportional to the speed of light in the medium.

Answer: **(B) It is inversely proportional to the speed of light in the medium.**

10. **The refractive index of a medium is highest for which color of light?**
    (A) Red (B) Green (C) Blue (D) Violet

Answer: **(D) Violet**

11. **If the refractive index of a medium is 1.5, what can be said about the speed of light in that medium compared to the speed in a vacuum?**
    (A) It is half the speed in a vacuum.
    (B) It is the same as the speed in a vacuum.

(C) It is twice the speed in a vacuum.
(D) It is three times the speed in a vacuum.

Answer: **(A) It is half the speed in a vacuum.**

12. How does the refractive index change with the density of a medium?

(A) Directly proportional
(B) Inversely proportional
(C) No relationship
(D) Exponential relationship

Answer: **(A) Directly proportional**

13. What is the relationship between dispersive power (D) and refractive index (μ) of a material?

(A) D ∝ μ (B) D = μ (C) D ∝ 1/μ (D) D = 1/μ

Answer: **(A) D ∝ μ**

14. What is the angle of deviation?

(A) The angle between incident and refracted rays
(B) The angle between incident and reflected rays
(C) The angle between the emergent ray and the incident ray
(D) The angle between the incident ray and the direction of minimum deviation

Answer: **(D) The angle between the incident ray and the direction of minimum deviation**

15. Which prism will produce the maximum angular dispersion?

(A) Equilateral prism (B) Isosceles prism
(C) Right-angled prism (D) Acute-angled prism

Answer: **(A) Equilateral prism**

16. Dispersive power of a material is defined as:

(A) The ability of a material to disperse light
(B) The ratio of angular dispersion to the angle of deviation
(C) The ratio of the angle of deviation to the wavelength of light

(D) The ability of a material to reflect light

Answer: **(B) The ratio of angular dispersion to the angle of deviation**

17. In which of the following cases will the dispersion of light be minimum?

(A) When the angle of incidence is small
(B) When the angle of incidence is large
(C) When the prism material has high dispersive power
(D) When the wavelength of light is short

Answer: **(D)When the angle of incidence is small**

18. Which of the following colours suffers maximum deviation?

(A) Orange (B) Green (C) Yellow (D) Blue

Answer: **(D) Blue** **[PYQ April 2022]**

19. Which of the following factors affect the angle of deviation?

(A) Angle of incidence and angle of emergence
(B) Angle of incidence and refractive index
(C) Wavelength and angle of emergence
(D) Wavelength and refractive index

Answer: **(D) Wavelength and refractive index**

20. A ray of light passing through a glass prism undergoes dispersion. What happens to the speed of light inside the prism?

(A) It increases (B) It decreases
(C) It remains constant (D) It depends on the color of light

Answer: **(D) It decreases**

21. The dispersive power of a medium is maximum when:

(A) Refractive index is minimum (B) Refractive index is maximum
(C) Wavelength is minimum (D) Wavelength is maximum

Answer: **(D) Wavelength is maximum**

22. What is responsible for the formation of a rainbow?

(A) Refraction and dispersion of light
(B) Reflection and interference of light
(C) Diffraction and scattering of light
(D) Polarization and dispersion of light

Answer: (A) Refraction and dispersion of light

23. According to Rayleigh's law, the scattering of light is inversely proportional to the:

(A) Wavelength of light
(B) Frequency of light
(C) Intensity of light
(D) Amplitude of light

Answer: (A) Wavelength of light

24. The phenomenon of scattering of light that causes the sky to appear blue is known as:

(A) Rayleigh scattering
(B) Raman scattering
(C) Mie scattering
(D) Tyndall scattering

Answer: (A) Rayleigh scattering

25. In the context of scattering of light, Rayleigh scattering is more effective for shorter wavelengths. Which color is scattered the most in this process?

(A) Red
(B) Green
(C) Violet
(D) Yellow

Answer: (C) Violet

26. The cause of the blue color of the ocean is: [sample paper]

(A) reflection
(B) scattering of light by water molecules
(C) total internal reflection
(D) refraction

Answer: (B) scattering of light by water molecules

27. What is the primary reason behind the reddish appearance of the Sun during sunrise and sunset?

(A) Rayleigh scattering
(B) Mie scattering
(C) Absorption of shorter wavelengths by the atmosphere

(D) Tyndall scattering

Answer: (A) Rayleigh scattering

28. The Raman effect is associated with:

(A) Absorption of light by a material

(B) Refraction of light through a prism

(C) Change in the frequency of scattered light

(D) Polarization of light

Answer: (C) Change in the frequency of scattered light

29. During the formation of a rainbow, what is the correct sequence of colors from the outer to the inner edge?

(A) Violet, Indigo, Blue, Green, Yellow, Orange, Red

(B) Red, Orange, Yellow, Green, Blue, Indigo, Violet

(C) Blue, Green, Yellow, Orange, Red, Violet, Indigo

(D) Red, Violet, Indigo, Blue, Green, Yellow, Orange

Answer: (B) Red, Orange, Yellow, Green, Blue, Indigo, Violet

30. The blue color of the sky is more pronounced at higher altitudes because:

(A) There is more pollution at higher altitudes

(B) The air density is higher at higher altitudes

(C) Rayleigh scattering is more effective at higher altitudes

(D) Mie scattering is more effective at higher altitudes

Answer: (C) Rayleigh scattering is more effective at higher altitudes

31. The phenomenon responsible for the blue colour of the sky is ___.

(A) Diffraction (B) Dispersion (C) Absorption (D) Scattering

Answer: (D) Scattering **[PYQ Jan 2021]**

32. The refracting angle of a prism is 30° and its refractive index is 1.6. Calculate the deviation caused by the prism.

(A) 28° (B) 8° (C) 30° (D) 18°

Answer: **(D) 18°**

② Complete the sentence using an appropriate word:

33. **Angle of deviation, dispersive power, dispersion, parallel, angular dispersion**

(a) When light passes through a prism, it undergoes ……………, resulting in the separation of colors.

(b) The angle formed between the incident ray and the direction of minimum deviation in a prism is known as the ……………

(c) The phenomenon where different colors of light are spread out at different angles by a prism is called ……………

(d) The ability of a material to disperse light is quantified by its ……………

(e) In a prism, the angle of minimum deviation occurs when the emergent ray is …………… to the incident ray.

Answer: **(a) dispersion, (b) Angle of deviation, (c) angular dispersion, (d) dispersive power, (e) parallel**

③ Fill in the blanks:

34. **Fill in the blanks:** [sample paper]

(i) A ray of light undergoes ___________ twice on passing through a prism.

(ii) ___________ is the most scattered colour.

(iii) The deviation through a prism is minimum when angle of incidence is equal to angle of ___________ .

(iv) According to Rayleigh’s law of scattering, The intensity of scattered light is inversely proportional to the ___________ power of its wavelength.

Answer: **(i) refraction, (ii) violet, (iii) emergence, (iv) fourth**

35. **Fill in the blanks.**

(i) The ___________ of a medium determines how much the light will be bent as it enters the medium.

(ii) The spread of colors in a rainbow occurs due to the ___________ of sunlight by raindrops.

(iii) phenomenon of splitting of light into its component colours is ___________

(iv) Very fine particles mainly scatter ___________ light.
(v) The phenomenon of change in the ___________ of light when it passes from one transparent medium to another is refraction.
(vi) The refractive index depends upon the ___________ of propagation of light in different media.

Answer: **(i) refractive index, (ii) dispersion, (iii) dispersion, (iv) blue, (v) direction, (vi) relative speed**

④ Match the following:

36. **Match column – I statement with the right option of column – II.**

Column I	Column II
(i) Most deviated colour	P. Yellow
(ii) Least deviate colour	Q. Red
	R. Orange
	S. Violet

Answer: **(i) – S, (ii) – Q** [sample paper]

37. **Match the statements of Column A with those of Column B.**

Column I	Column II
(A) Blue color of sky	(a) Total internal reflection
(B) Mirage	(b) Scattering of light
(C) Twinkling of stars	(c) Dispersion
(D) Formation of rainbow	(d) Refraction

Answer: **A – (b), B – (a), C – (d), D – (c)**

⑤ True or False:

38. The refractive index of a medium is independent of the wavelength of light.

⇒ False.

39. Angular dispersion refers to the spread of colors in a spectrum.

⇒ True.

40. The angle of deviation is the angle formed between the incident ray and the direction of maximum deviation in a prism.

⇒ False.

41. Dispersion occurs when different colors of light travel at the same speed through a medium.

⇒ False.

42. A higher refractive index of a medium indicates a lower speed of light in that medium.

⇒ True.

43. The dispersive power of a material is the same for all colors of light.

⇒ False.

44. The angle of deviation is the same for all wavelengths of light passing through a prism.

⇒ False.

45. The dispersive power is lower for materials with a lower refractive index.

⇒ True.

46. In a rainbow, the outer edge corresponds to the color with the highest wavelength.

⇒ False.

47. The Raman effect is related to the change in the direction of light as it passes through a medium.

⇒ False.

❻ Very short type question [2 marks of each]:

48. **Explain the significance of the dispersive power of a material.**

Answer: The dispersive power indicates the ability of a material to spread out different colors of light, and it quantifies the extent of dispersion that can be achieved with that material.

49. Why can't we see clearly through the fog? Name the phenomenon responsible for it.

Answer: During fog, the light coming from an object is partly deflected by the particles of the fog and does not reach the eye of the observer. For that reason, we cannot see the objects clearly through fog. This responsible phenomenon is called the scattering of light.

50. Why is red light always used as a danger signal?

Answer: Red light always used as a danger signal because the wavelength of red light is maximum. The intensity of scattered light is inversely proportional to the fourth power of wavelength. So, red light is scattered much less than green or blue light while passing through the dust particles floating in air. The red light can be seen from long distances as a necessary caution

51. Does dispersion of light take place In a vacuum?

Answer: No, dispersion of light does not take place in a vacuum because light of all colours has the same velocity in a vacuum.

52. What will be the nature of the spectrum formed from the following Source the sun, an electric bulb, a neon bulb and sodium salt in a Bunsen flame?

Answer: Sun: Line absorption spectrum.

Electric bulbs: Continuous emission spectrum.

Neon bulb: Band emission spectrum

Sodium salt in Bunsen flame: Line emission spectrum.

53. Can the dispersive power of a material medium be negative?

Answer: No, it cannot be negative, as the refractive index for violet light is always greater than that for red light. Also, refractive index is inversely proportional to. The sign of ω will be positive, as is still greater than 1 and as.

54. How does the angle of minimum deviation of a glass prism vary, if the incident violet light is replaced with red light?

Answer: We know that $\lambda_{\text{red}} > \lambda_{\text{violet}}$

therefore $\mu_{\text{red}} < \mu_{\text{violet}}$ and hence $\delta_{\text{red}} < \delta_{\text{violet}}$.
When incident violet light is replaced with red light, the angle of minimum deviation of a glass decreases.

55. How does the angle of minimum deviation of a glass prism of refractive index 1.5 change, if it is immersed in a liquid of refractive index 1.3?

Answer:

Here ${}^{a}\mu_{g} = 1.5$ and ${}^{a}\mu_{w} = 1.3$

$\because \quad \delta = (\mu - 1)\,A$

For deviation in air, $\mu = \dfrac{\mu_g}{\mu_a} = \dfrac{1.5}{1} = 1.5$

$\therefore \quad \delta = (1.5 - 1) \times 60^\circ = 30^\circ$

For deviation in water, $\mu = \dfrac{\mu_g}{\mu_w} = \dfrac{1.5}{1.3} = 1.15$

$\therefore \quad \delta = (1.15 - 1) \times 60^\circ = 0.15 \times 60^\circ = \mathbf{9^\circ}$

Hence angle of deviation is decreased.

⑦ Short type question [3 marks of each]:

56. A tree having green leaves and red flowers is observed by lighting it successively in green, red and blue light. What will be the colours of the leaves and the flowers in each case?

Answer: When the tree is illuminated with green light the leaves will reflect green light. So the leaves look green. The red flowers absorb all colours except red. So in this case the green light will be absorbed by the flowers. No light will come to the eyes of the observer. Hence, the flowers will look dark.

When the tree is illuminated with red light the green leaves will absorb the red light. So the leaves will look black. The flowers will reflect the incident red light. So they will look red. If the tree is illuminated with blue light, it will be absorbed by both the leaves and the flowers. So in this case both the leaves and the flowers will look dark.

57. A ray of light passing through an equilateral triangular glass prism from air undergoes minimum deviation when angle of incidence is 3/4th of the angle of prism. Calculate the speed of light in the prism.

Answer:

Given : $i = \frac{3}{4}\text{A}$ where $\left[\begin{array}{l} i = \text{angle of incidence} \\ \text{A} = \text{angle of prism} \end{array}\right.$

$$\text{We know, } \mu = \frac{\sin\left(\frac{\text{A}+\delta_m}{2}\right)}{\sin\frac{\text{A}}{2}}$$

...where $[\delta_m$ = angle of minimum deviation

$$\text{or} \quad \frac{C_1}{C_2} = \frac{\sin\left(\frac{\text{A}+\delta_m}{2}\right)}{\sin\frac{\text{A}}{2}}$$

$$\text{or} \quad \delta_m = 2i - \text{A} = 2 \times \frac{3}{4}\text{A} - \text{A} = \frac{\text{A}}{2}$$

$$\delta_m = \frac{60^\circ}{2} = 30^\circ \quad \Rightarrow \frac{C_1}{C_2} = \frac{\sin 45^\circ}{\sin 30^\circ} = \sqrt{2}$$

58.

(a) The bluish colour predominates in clear sky.

(b) Violet colour is seen at the bottom of the spectrum when white light is dispersed by a prism.

State reasons to explain these observations.

Answer:

(a) The scattering of light by the atmosphere is colour dependent. According to Rayleigh's law, the intensity of scattered light, $I \propto \frac{1}{\lambda^4}$

Blue light is scattered much more strongly than red light. The blue component of light is proportionately more in the light coming from different parts of the sky. This gives the impression of the blue sky.

(b) As refractive index of prism is different for different colours, therefore, different colours deviate through different angles on passing through the prism. As $\lambda_{violet} < \lambda_{red}$ therefore $\mu_{violet} > \mu_{red}$. Hence $\delta_{violet} > \delta_{red}$ maximum deviation is of violet colour. That is why violet colour, is seen at the bottom of the spectrum when white light is dispersed by a prism.

59. Why do most ordinary gases not show dispersion with white light?

[PYQ April 2022]

Answer: In most ordinary gases, the velocity of propagation of waves of different wavelengths of white light is almost the same. The waves having a different velocity of propagation than the wavelengths of the white lights are having the tendency to refract and disperse the light.

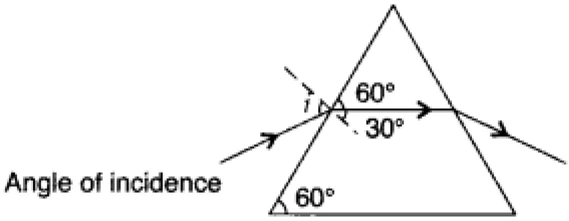
For the gases that do not show dispersion with white light, the refractive index is very close to 1.

Hence, most ordinary gases do not show dispersion with white light because the velocity of propagation of waves of different wavelengths of visible light is almost the same.

60. A ray of light, incident on an equilateral glass prism ($\mu_g = \sqrt{3}$) moves parallel to the base line of the prism inside it. Find the angle of incidence for this ray.

Answer: $\mu_g = \sqrt{3} = {}_1n_2$

$${}_1n_2 = \frac{\sin i}{\sin r} \qquad \therefore \sqrt{3} = \frac{\sin i}{\sin 30°}$$



$$\Rightarrow \sin i = \sqrt{3} \times \sin 30° = \sqrt{3} \times \frac{1}{2} = \frac{1.732}{2}$$

$$\Rightarrow \sin i = 0.866$$

∴ Angle of incidence, i = 60°

61. Explain the following, giving reasons: **[PYQ Oct 2022]**

(i) Sky appears blue when viewed from earth, and dark when viewed from space.

(ii) Sun appears red at the time of sunrise.

Answer:

(i) There is no atmosphere in the outer space. We see the sky blue because scattering happens due to the particles in the atmosphere. The reason for scattering of light is the colloidal particles in the atmosphere which refract the light in different directions. When the blue light is refracted, this light comes to our eyes and thus the sky appears blue. Whereas, in space, as there is no atmosphere, light cannot be scattered. Due to this the sky appears dark to an astronaut.

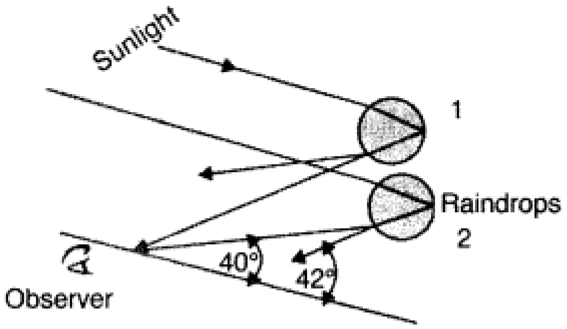
(ii) Red light scatters the least by the molecules present in the air. So at sunrise and sunset, the sunlight travels a longer path through the atmosphere to reach our eyes. The blue light scatters the most and has been mostly removed, leaving the red light remaining which reaches our eyes, hence it appears red.

62. Write the conditions for observing a rainbow. Show, by drawing suitable diagrams, how one understands the formation of a rainbow.

Answer: The conditions for observing a rainbow are:

1. The Sun comes out after a rainfall.
2. The observer stands with the Sun towards his/her back.

Formation of a rainbow



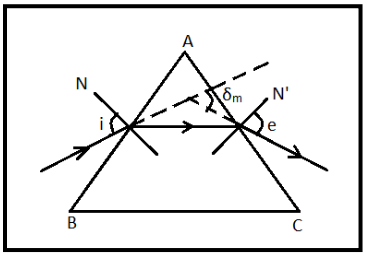
The rays of light reach the observer through a refraction, followed by a reflection followed by a refraction.

Figure shows red light from drop 1 and violet light from drop 2, reaching the observer's eye.

63. **(a) Drawing a labelled ray diagram, show the refraction of a ray of light passing through an equiangular triangular prism. Plot a graph showing the variation of angle of deviation with the angle of incidence.**

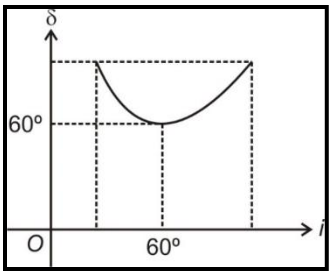
(b) Calculate the refractive index of the material of an equilateral triangular prism for which angle of minimum deviation is 60°. [PYQ Oct 2022]

Answer: **(a)**



The above diagram shows the path of light traced when it passes through a prism such that the angle of deviation of light is minimum.

Graph showing the variation of angle of deviation with the angle of incidence is:



(b) we are given: A = 60°, δ_m = 60°

We are to calculate μ

We know that $\mu = \dfrac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$

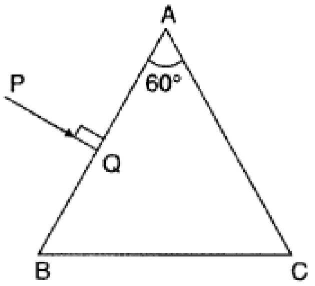
$$\Rightarrow \mu = \frac{\sin\left(\frac{60^\circ+60^\circ}{2}\right)}{\sin\left(\frac{60^\circ}{2}\right)} = \sqrt{3}$$

64. **Explain why dispersion of white light does not take place by using a rectangular slab of glass instead of a prism.**

Answer: Dispersion of white light does not take place when it is refracted through a rectangular glass slab instead of a prism. This type of glass slab may be considered as a combination of two similar prisms P_1 and P_2

The refracting faces of the two prisms are parallel to each other, but the bases of the prisms are situated opposite to each other. White light passing through the prism Pj produces spectrum but the different colours of the spectrum again recombine after passing through the prism P_2. As a result, the emergent ray becomes white

65. A ray PQ is incident normally on the face AB of a triangular prism of refracting angle of 60°, made of a transparent material of refractive index $2/\sqrt{3}$, as shown in the figure. Trace the path of the ray as it passes through the prism. Also calculate the angle of emergence and angle of deviation.



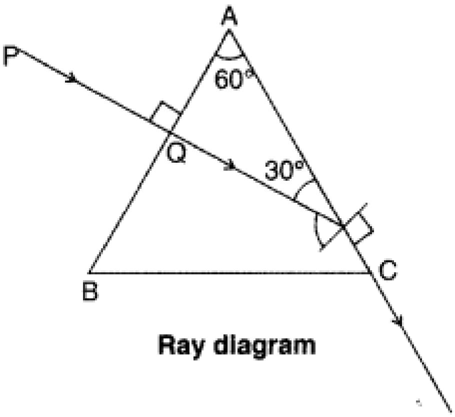
Answer:

If i_c is the critical angle for the prism/material,

$$\mu = \frac{1}{\sin i_c}$$

$$\therefore \quad \sin i_c = \frac{1}{\mu} = \frac{\sqrt{3}}{2} \qquad \Rightarrow \qquad i_c = 60°$$

Angle of incidence at face AC of the prism = 60°



Ray diagram

Hence, refracted ray grazes the surface AC as $i_c = i$
∴ Angle of emergence = 90°
and Angle of deviation = 30°

⑧ Long type question [4 marks of each]:

66. A ray of white light is allowed to pass through a hollow prism made by parallel glass plates. Will any spectrum be produced? Explain with figure

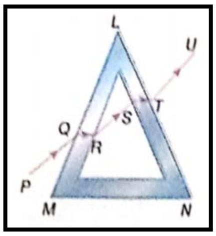
Answer: A ray of white light is allowed to pass through a hollow prism made by parallel glass plates.

A spectrum will not be produced if a ray of white light is allowed to pass through a hollow prism. The path of a ray of white light through a hollow prism Is shown. The two refracting faces LM and LN of the hollow prism are two parallel glass plates.

A ray of light PQ Is refracted In the glass along QR after incidence on the face LM and moves along RS parallel to lQ. As the prism is hollow the ray RS

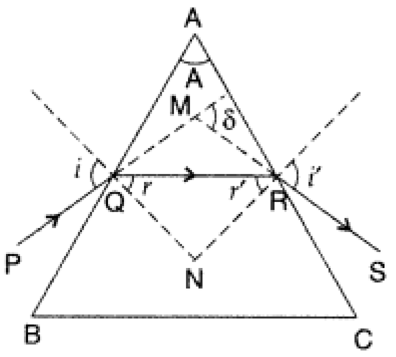
As the prism is hollow the ray RS is incident on the second refracting face LN. The ray is refracted along ST and emerges from the prism along TU Parallel to PQ.

As the rays of all colours trim the same white Is note merge direction, the light produced from takes node place dispersion prism rays. So of along spectrum is not produced



67. Draw a ray diagram showing the path of a ray of light entering through a triangular glass prism. Deduce the expression for the refractive index of glass prism in terms of the angle of minimum deviation and angle of the prism.

Answer: A ray PQ is incident on the face AB of prism at ∠i and effected along QR at ∠r. The angle of incidence (from glass to air) to the second face is Y and the angle of refraction or emergence is i'.



The angle between the emergent ray RS and incident ray in the direction PQ is called the angle of deviation δ.

In the quadrilateral AQNR,

$\angle Q$ and $\angle R$ are right angles

$\therefore \quad \angle A + \angle QNR = 180^\circ \qquad \ldots(i)$

and in ΔQNR

$r + r' + \angle QNR = 180^\circ \qquad \ldots(ii)$

Comparing these equations, we get

$r + r' = \angle A$

Also $\delta = \angle MQR + \angle MRQ = i - r + i' - r'$

$= i + i' - (r + r')$

$\therefore \quad \delta = i + i' - \angle A$

In the minimum deviation position, $i = i'$, $r = r'$ and $\delta = \delta_m$

$\because \quad r + r = A \qquad \therefore\ r = \frac{A}{2}$

and $\delta_m = i + i - A \qquad \therefore\ i = \frac{A\delta_m}{2}$

68. Write expression for dispersive power of the material of a prism and hence explain the following:

(i) How does the width of the spectrum depend on dispersive power?

(ii) How does the width of spectrum depend on the angle of prism?

(iii) Out of crown glass and flint glass, flint glass is preferred for a prism and crown glass for a lens. Why? **[PYQ Jan 2021]**

Answer: If δv and δr are the deviations produced for the violet and red rays and μv and μr are the corresponding refractive indices of the material of the small angled prism

then angular dispersion (difference in deviation between the extreme colors) is given by: $\delta v - \delta r = (\mu v - \mu r)A$

Similarly deviation for yellow light is given by $\delta y = (\mu y - 1)A$

Now dispersive power (ω) of the material is defined as (ω) = $\delta y \delta v - \delta r$.

Thus $\omega = (\mu y - 1)A\ (\mu v - \mu r)A = (\mu y - 1)(\mu v - \mu r)$

(i) The width of the spectrum increases with an increase in the dispersive power.

(ii) Angle of dispersion depends on Angle of the prism, the material of the prism and the wavelength of light passing through it.

(vii) Refractive index of flint glass is 1.62 which is more than that of crown glass which is 1.52. Thus, flint glass will bend the ray more as compared to crown glass and hence, a greater angle of deviation.

69. State the Difference between Dispersion and Scattering of Light.

Answer:

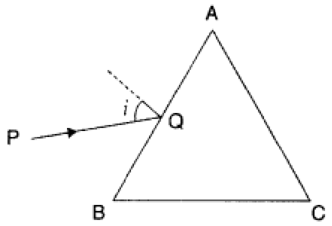
Dispersion	Scattering
1. It is the splitting of white light into its constituent colours.	Light scattering is defined as the deviation of light rays from their straight trajectory.
2. White light is made up of several constituents with varying wavelengths (it contains light of different colours).	As light travels through the atmosphere, it follows a straight path until it encounters obstructions such as gas molecules and dust particles.
3. A white light beam passes through a medium, which splits the white light into different components.	Scattering is the process by which light is deflected by tiny particles in the medium through which it travels.

⑨ Very short type question [5 marks of each]:

70. A ray ‘PQ’ of light is incident on the face AB of a glass prism ABC (as shown in the figure) and emerges out of the face AC. Trace the path of the ray. Show that $\angle i + \angle e = \angle A + \angle \delta$

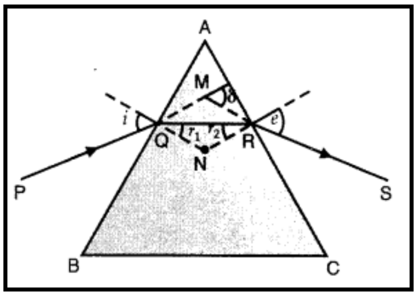
where δ and e denote the angle of deviation and angle of emergence respectively.

Plot a graph showing the variation of the angle of deviation as a function of angle of incidence. State the condition under which ∠δ is minimum.



Answer: The figure shows the passage of light through a triangular prism ABC.

The angles of incidence and refraction at the first face AB are ‘i' and ‘r_1’ while the angle of incidence (from glass to air) at the second face AC is ‘r_2’ and the angle of refraction or emergence ‘e’. The angle between the emergent ray RS and the direction of the incident ray PQ is called the angle of deviation δ.



In the quadrilateral AQNR, two of the angles (at the vertices Q and R) are right angles. Therefore, the sum of the other angles of the quadrilateral is 180°.

$$\angle A + \angle QNR = 180^\circ$$

From the triangle

$$r_1 + r_2 + \angle QNR = 180^\circ$$

Comparing these two equations, we get

$r_1 + r_2 = A$

The total deviation 8 is the sum of deviations at the two faces,

$$\delta = (i - r_1) + (e - r_2)$$

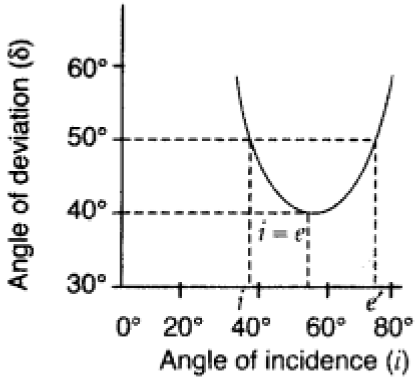
that is

$$\delta = i + e \quad \text{or} \quad \angle i + \angle e = \angle A + \delta \qquad \ldots(i)$$

A plot between the angle of deviation and angle of incidence is shown in the figure. In general, any given value of δ, except for i = e, corresponds to two values i and hence of e. This, in fact, is expected from the symmetry of i and e in equation (i) above, i.e., δ remains the same if i and e are. interchanged. Physically, this is related to the fact that the path of ray in the diagram above can be traced back, resulting in the same angle of deviation. At the minimum deviation dm, the refracted ray inside the prism becomes parallel to its base. We have, $\delta = \delta_m$

When angle of incidence (i) and angle of emergence (e) are equal, ie,

$\angle i = \angle e$



71. **Sir C.V. Raman was awarded Nobel prize in Physics in 1930 for the discovery of 'Raman Effect'.**

(a) State 'Raman Effect', with its simple theoretical explanation.

(b) Calculate refractive index of an equilateral prism, if the angle of minimum deviation is equal to the angle of prism. **[PYQ Jan 2021 & Oct 2021]**

Answer:

(a) The Raman Effect is a phenomenon in spectroscopy discovered by Sir C. V. Raman in 1928. It involves the inelastic scattering of light when it interacts with matter, such as molecules or crystals. In simple terms, when light interacts with a sample, most of it is scattered in the same frequency as the incident light (Rayleigh scattering). Still, a small fraction of the scattered light has a different frequency, and this shift in frequency is known as the Raman shift.

(b) Refractive index of prism is $\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$

Given: A= 60 ° [equilateral prism] and

Angle of minimum deviation is equal to the Angle of the prism $\Rightarrow A = \delta_m$

$$\Rightarrow \mu = \frac{\sin\left(\frac{60^\circ+60^\circ}{2}\right)}{\sin\left(\frac{60^\circ}{2}\right)} = \sqrt{3}$$

72.

(a) Explain the phenomenon of 'scattering of light'.
(b) State 'Rayleigh's law of scattering'.
(c) Explain the red colour of the sun at sunrise and sunset. Draw a diagram.

[PYQ Oct 2021]

Answer:

(a) Scattering of light is the phenomenon in which light rays get deviated from its straight path on striking an obstacle like dust or gas molecules, water vapours etc. Scattering of light gives rise to many spectacular phenomena such as Tyndall effect and the "red hues of sunrise and sunset".

(b) Rayleigh scattering is the scattering of light by the particles present in the atmosphere. According to Rayleigh's scattering law, the amount of scattering of the light is inversely proportional to the fourth power of the wavelength. From the relation between scattering and wavelength, we understand that shorter wavelengths scatter more. Since blue light has a lesser wavelength than red light it scatters more.

(c) Due to atmospheric scattering, blue light is scattered the most while red light is scattered the least.

During day, red light is not scattered as the light travels lesser distance and scattering of blue light by the atmosphere makes it appear blue.

During sunrise/sunset, when the Sun is near the horizon, sunlight has to travel a larger distance and blue light is scattered away. Since the red light is scattered less, it can travel longer distances and hence, sun appears reddish during sunrise/sunset.

22

Wave phenomena and light

Short summary

What do we learn

Quick Revision

➢ *Introduction*

We all know that light have two natures –:

1. Particle nature

2. Wave nature

Wave nature of light is postulated and discovered by the great physicist **HUYGENS**.

So in this chapter we have to study about Huygens' Principle, interference, diffraction and polarization of light.

➢ *Wave optics*

It describes the connection between waves and rays of light.

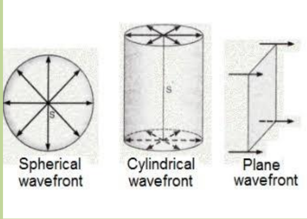
According to the wave theory of light, light is a form of energy which travels through a medium in the form of transverse wave.

- The laws of reflection and refraction can be verified using Huygens' theory. (see in complete notes)
- To know the Huygens' Principle we have to know some important terms related to this which are given here.

➢ *Wave front*

It is defined as the surface of wave on which medium particles vibrates in same phase, i.e. wave front is the surface of constant phase.

The shape of wave front due to a
(i) Point source is spherical
(ii) Line source is cylindrical
(iii) Source at infinity is a plane.



- Since phase on wave front is same therefore phase difference between any two point on wave front is zero.
- Ray of light is perpendicular to wave front.

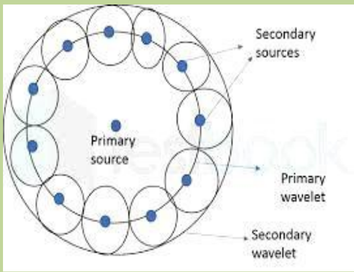
➢ *Secondary source*

According to Huygens every points of wave front behaves like a source known as **secondary source.**

➢ *Secondary wavelets*

Wave front originating from secondary source is known as **secondary wavelets**.

➢ Secondary source & wavelets


Secondary sources
Primary source
Primary wavelet
Secondary wavelet

According to Huygens light wave propagates due to successive production of secondary wavelets and formation of new wave front.

➢ Wave speed

The speed by which wave front moves outward from the source is known as wave speed. It is also called as phase speed.

➢ Huygens' principle

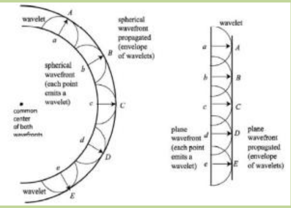
This is essentially a geometrical construction, which gives shape of the wave front at any time.

According to Huygens' principle,
(i) Every point on a wave front behaves like a light source and emits secondary wavelets.
(ii) The secondary wavelets spread in all directions in space (vacuum) with the velocity of light.
(iii) The envelope of wave front of secondary wavelets, after a given time, along forward direction gives the new position of wave front.

Huygens' wave theory successfully explains the phenomenon of interference, diffraction and polarization.

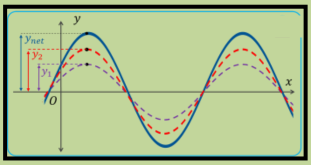
➢ Propagation of waves

Huygens principle is a method of analysis applied to wave propagation problems both in the far-field limit and near-field diffraction and reflection.
It states that: **"Every point on a wave front is in itself the source of spherical wavelets which spread out in the forward direction at the speed of light."**


wavelet
A
a
spherical wavefront propagated (envelope of wavelets)
B
spherical wavefront (each point emits a wavelet)
b
c
C
common center of both wavefronts
d
D
e
E
wavelet
wavelet
a
A
b
B
c
C
plane wavefront (each point emits a wavelet)
d
D
e
E
plane wavefront propagated (envelope of wavelets)

➢ superposition of light

In space two or more than two wave travels in space without disturbing each other.
At the time of superposition the displacement of medium particle is vector sum of individual.



If displacement of both waves in same direction then resulting displacement is $\mathbf{y = y_1 + y_2}$.

& In opposite direction is $\mathbf{y = y_1 - y_2}$.

➢ *Interference of light*

Definition:

When two wave travelling in same direction having same frequency, wavelength and amplitude and also wave should be originating **coherent source** then due to superposition of light wave alternating maximum and minimum intensity or amplitude found, this phenomenon is known as **"Interference of light"**.

➢ *Some important terms*

Amplitude: Amplitude of a wave refers to the maximum amount of displacement of a particle on the medium from its rest position or it is the distance from rest to crest or rest to trough.

Intensity: It is defined to be the power per unit area carried by a wave. $\boxed{I = PA}$

Frequency:

Frequency (υ) = 1/ time

Phase: Phase is the location or timing of a point within a wave cycle of a repetitive waveform.

Phase difference: Phase difference is the difference of phase of two points.

➢ *Coherent sources*

If during the propagation of wave phase difference between any two points remains same then the two source is known as **Coherent source** of each other.

- Two independent sources cannot be coherent source.
- Two coherent sources can be obtained from a single parent source.

➢ *Conditions of interference*

❶ light source be travel in same direction.

❷ light should be travel in same direction.

❸ frequency and wavelength should be equal.

❹ Amplitude of two light wave should be equal or approximately equal.

➢ *Value of resulting amplitude and intensity* (I)

$$\boxed{A = \sqrt{A_1^2 + A_2^2 + 2A_1A_2 \cos \emptyset}}$$

$$\Rightarrow \boxed{A = 2A_0 \cos \emptyset_2}$$

$$\boxed{I = 4I_0 \cos^2\left(\frac{\emptyset}{2}\right)}$$

➢ Destructive interference

The point where minimum intensity or amplitude obtained at that point interference is called **Destructive interference**.

$\Rightarrow$ $\theta = \pi, 3\pi, 5\pi, 7\pi, 9\pi, 11\pi, \ldots\ldots$

Or θ = odd π Or $\theta = (2n + 1)\pi$

$$A_{min} = A_1 - A_2$$

Note: If $A_1 = A_2 = A_0$ then $A_{min} = 0$.

$$I_{min} = \left(\sqrt{I_1 - I_2}\right)^2$$

NOTE: If $I_1 = I_2 = I_0$ then $I_{min} = 0$.

Path difference = 2π × Phase difference

$$\Rightarrow \Delta x = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, \ldots..$$

➢ Constructive interference

The point where maximum intensity or amplitude obtained of that point interference is called as **Constructive interference**.

$\Rightarrow$ $\emptyset = 0, 2\pi, 4\pi, 6\pi, 8\pi, \ldots.$

Or $\emptyset$ = even π Or $\emptyset = 2n\pi$

$$A_{max} = A_1 + A_2$$

Note: If $A_1 = A_2 = A_0$ then $A_{max} = 2A_0$

$$I_{max} = \left(\sqrt{I_1 - I_2}\right)^2$$

NOTE: If $I_1 = I_2 = I_0$ then $I_{max} = 4I_0$

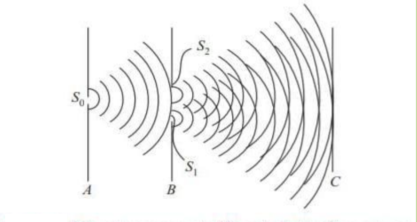
Path difference = $\frac{\lambda}{2\pi}$× Phase difference

$$\Rightarrow \Delta x = 0, \lambda, 2\lambda, 3\lambda, 4\lambda, \ldots\ldots.$$

➢ Young's double slit experiment

In 1801 scientist "**Euygene Thomas young"** shows the phenomenon of interference of light.

He proved light is a wave with double slit experiment. This experiment is also known as young's double slit experiment.



Schematic arrangement of Young's double-slit experiment

Fringe: On screen alternating bright & dark circular pattern are formed, this pattern is called as fringe.

$$\Delta x = \frac{yd}{D}$$

In this experiment, at the centre of screen bright pattern is formed. so it is called as **central bright**.

The pattern is central bright, 1st dark, 1st bright, 2nd dark, 2nd bright…

∗ For maximum intensity or for constructive interference –:

We know that maximum intensity gives bright. Therefore position of bright fringe: $\mathbf{0, \frac{D\lambda}{d}, 2\left[\frac{D\lambda}{d}\right], 3\left[\frac{D\lambda}{d}\right], \ldots.}$

∗ For minimum intensity or for destructive interference –:

We know that maximum intensity gives dark. Therefore position of bright fringe: $\mathbf{0, \frac{D\lambda}{2d}, \left[\frac{3D\lambda}{2d}\right], \left[\frac{5D\lambda}{2d}\right], \ldots.}$

➢ *YDSE*

- Fringe width:

Bright fringe width = Dark fringe width = $\frac{D\lambda}{d}$

- Position of n_{th} bright fringe = $\frac{nD\lambda}{d}$
- Position of n_{th} dark fringe = $\left(n+\frac{1}{2}\right)\frac{D\lambda}{d}$

n = 0, $\pm$1, $\pm$2, $\pm$3,……

- Number of bright fringe: $N_{max-}= \left[\frac{d}{\lambda}\right]$
- Number of dark fringe: $N_{min}= \left[\frac{d}{\lambda}+\frac{1}{2}\right]$

➢ *Effect of changes made in young's Aperture on the fringe width*

1. Fringe width ∝ D (Distance between screen)
2. Fringe width ∝ $\frac{1}{d}$ (Distance between slit)
3. Fringe width ∝ λ.

⇒Fringe width $R > 0 > Y > G > B > I > V$

4. If whole system is placed in liquid of a specific or different (RI) μ So, fringe width reduces & it becomes 1μ times of its value in air.

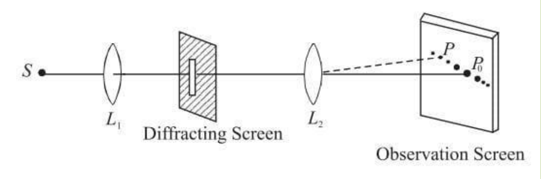
$$\boxed{\omega_{liquid}\ \frac{\omega_{air}}{\mu_{liquid}}}$$

5. If one of the two identical slits S_1 & S_2 be wrapped with black clothes. Then there is no interface fringe in the uniform illumination on the screen.

➢ *Diffraction of light*

"The phenomenon of bending of light around the edges (corners) of an obstacle or aperture is called Diffraction of light."

➢ *Diffraction by single slit*



Schematic representation of single slit dtiffraction

For n^{th} bright

Angular position = $\left(n+\frac{1}{2}\right)\frac{\lambda}{a}$

➢ *Polarization of light*

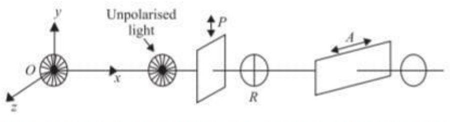
"The phenomenon of districting the oscillation of wave to just one direction in the transverse plane is called Polarization of light."

Plane of vibrations: A plane containing the vibrations of polarized light is called plane of vibration.

Plane of polarization: A plane perpendicular to the plane of vibration is called plane of polarization.

NOTE: Polarization can take place only in Transverse waves.

➢ Polarization


y
Unpolarised light
P
O
x
z
R
A

Schematics of the apparatus for observing polarisation of light

Polaroid: It is a polarizing film mounted between two glass plates. It is used to produce polarized light.

➢ Law of malus

It states –:

"when a beam of plane polarized light is passed through analyser the intensity I of transmitted light varies directly of square of the cosine of angle θ between polarizer and analyser."

$$I \propto \cos^2\theta$$

$$\Rightarrow \boxed{I = I_0 \cos^2\theta}$$

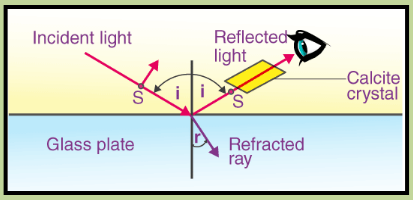
➢ Brewster's law

When unpolarized light is incident at an angle of polarization (i_p) on the interference separating air from a medium of refractive index μ, then reflected light becomes fully polarized, provided

$$\mu = \tan i_p$$

$$\Rightarrow \boxed{i_P = \tan^{-1}(\mu)}$$

It states that ***"the tangent of the polarizing angle of incidence of transparent medium is equal to the refracted index."***


Incident light
Reflected light
Calcite crystal
S
i
i
S
Glass plate
r
Refracted ray

Question – Answer

❶ MCQs

1. In wave optics, a wave front is defined as:

(A) The locus of all points vibrating in phase
(B) A line connecting all points with the same amplitude
(C) The direction of wave propagation
(D) The intersection of two waves

Answer: (A) The locus of all points vibrating in phase.

2. Which of the following best describes a secondary source of light waves?

(A) A source that produces its own light
(B) A source that reflects light from a primary source
(C) A source that emits light due to the influence of another wave
(D) A source that scatters light in all directions

Answer: (C) A source that emits light due to the influence of another wave.

3. The Huygens principle states that every point on a wavefront:

(A) Acts as a secondary source of spherical waves
(B) Reflects incident waves in the same direction
(C) Produces coherent light waves
(D) Absorbs energy without re-emission

Answer: (A) Acts as a secondary source of spherical waves

4. When light passes through an opening or around an obstacle, it exhibits:

(A) Diffraction (B) Interference (C) Refraction (D) Polarization

Answer: (A) Diffraction

5. The speed of light in a medium is determined by its:

(A) Frequency (B) Amplitude
(C) Wavelength (D) Refractive index

Answer: (D) Refractive index

6. **According to Huygens principle, the secondary wavelets emitted from different points on a wavefront:**
   (A) Have the same amplitude and frequency
   (B) Have the same frequency but different amplitudes
   (C) Have the same amplitude but different frequencies
   (D) Have both different amplitudes and frequencies

Answer: (A) Have the same amplitude and frequency

7. **The phenomenon of interference is associated with the interaction of:**
   (A) Two different waves
   (B) Waves of different amplitudes
   (C) Waves of different frequencies
   (D) Two or more coherent waves

Answer: (D) Two or more coherent waves

8. **When light waves superpose constructively, it leads to:**
   (A) Destructive interference (B) Increased amplitude
   (C) Polarization (D) Diffraction

Answer: (B) Increased amplitude

9. **In wave optics, the term "coherent sources" refers to sources that have:**
   (A) Similar frequencies (B) Similar amplitudes
   (C) Constant phase difference (D) Different wavelengths

Answer: (C) Constant phase difference

10. **When two waves arrive at a point in opposite phases, leading to a decrease in amplitude, it is known as:**
   (A) Constructive interference (B) Destructive interference
   (C) Polarization (D) Diffraction

Answer: (B) Destructive interference

11. **The condition for constructive interference in light waves is that the path difference between the waves is:**
   (A) An odd multiple of half-wavelength

(B) An even multiple of half-wavelength
(C) An odd multiple of full wavelength
(D) An even multiple of full wavelength

Answer: (C) An odd multiple of full wavelength

12. What is the locus of all particles in a medium vibrating in the same phase called?

(A) Fringe (B) Wavelet (C) Wavefront (D) None of the above

Answer: (C) Wavefront

13. Which of the following factors does the intensity of light depend on?
(A) Frequency (B) Wavelength (C) Amplitude (D) Velocity

Answer: (C) Amplitude

14. Which of the following light phenomena confirms the transverse nature of light?
(A) Refraction of light (B) Diffraction of light
(C) Dispersion of light (D) Polarization of light

Answer: (D) Polarization of light

15. Polaroid glasses are used in sunglasses because
(A) They are cheaper
(B) They have a good colour
(C) They look fashionable
(D) They reduce the light intensity to half on account of polarization

Answer: (D) They reduce the light intensity to half on account of polarization

16. Two light sources are said to be coherent when both the sources of light emit light of
(A) The same amplitude and phase
(B) The same intensity and wavelength
(C) The same speed
(D) The same wavelength and constant phase difference

Answer: (D) The same wavelength and constant phase difference

17. Which of the following is an application of the Doppler Effect?

(A) Doppler Radius (B) Doppler Spectrometer
(C) Doppler Velocimeter (D) All of the above

Answer: (D) All of the above

18. Who discovered Poisson's bright spot?

(A) Fresnel (B) Rayleigh (C) Fraunhofer (D) Poisson

Answer: (D) Poisson

19. Which of the following is conserved when light waves interfere?

(A) Intensity (B) Amplitude (C) Phase (D) None of the above

Answer: (D) None of the above

20. Shape of wavelet formed by a line source is:

(A) Spherical (B) Cylindrical (C) Planer (D) None of this

Answer: (B) Cylindrical

❷ Complete the sentence using an appropriate word:

21. **[Interference, Oscillations, fringes, transverse, refractive index]**

1. When light passes through a narrow slit, it diffracts, producing a pattern of alternating light and dark …………… on a screen placed behind it.
2. The phenomenon of interference occurs when two or more light waves overlap, resulting in the formation of …………… bands.
3. Polarization of light refers to the alignment of the …………… of light waves in a particular direction.
4. Dispersion is the separation of light into its constituent colors due to variations in the …………… of the medium.
5. The phenomenon of polarization shows that light has …………… nature.

Answer: (1) fringes, (2) interference, (3) oscillations, (4) refractive index, (5) transverse

❸ Fill in the blanks:

22.

1. Huygens' postulated that light is a …………
2. A ………… of light emits cylindrical wavefronts.
3. The width of the central spot is ……….. the width of other spots.
4. The spot at the …………. is the brightest.
5. ………… law implies that polarising angle i_p depends on the refractive index of the material.

Answer: **(1) wave, (2) line source, (3) twice, (4) center, (5) brewster's**

❹ Match the following:

23. Match the statement of column I with the suitable statement of column II.

Column I	Column II
(1) Huygen's principle	p. Polarization
(2) Brewster's law	q. Amplitude
(3) Intensity depends on	r. Principle of superposition
(4) Line source	s. Cylindrical wavelet
(5) Point source	t. Spherical wavelet

Answer: **(1) – r , (2) – p, (3) – q, (4) – s, (5) - t**

24. Match the statement of column I with the suitable statement of column II.

Column I	Column II
1. The phenomenon of redistribution of light energy on account of superimposition	(a) Coherent source
2. Emit continuous light waves of same wavelength having constant phase difference	(b) Diffraction of light
3. The phenomena of bending light around the corners	(c) Polarization of light
4. The phenomena of restricting the vibration of ordinary light	(d) Interference of light

Answer: **1 – (d), 2 – (a), 3 – (b), 4 – (c)**

❺ True or false:

25. In Young's double-slit experiment, the central bright fringe is the result of constructive interference.

⇒ True

26. Huygens' principle states that every point on a wavefront acts as a source of secondary wavelets that spread out in all directions.

⇒ True

27. Single-slit diffraction produces interference fringes due to the superposition of waves passing through adjacent slits.

⇒ False

28. Polarization of light refers to the orientation of electric field vectors perpendicular to the direction of wave propagation.

⇒ True

29. Brewster's angle is the angle of incidence at which the reflected light is completely polarized parallel to the surface.

⇒ True

30. Diffraction gratings produce interference patterns due to the constructive and destructive interference of light passing through multiple slits.

⇒True

31. Newton's rings are a result of interference between light waves reflected from the surfaces of two closely spaced transparent media.

⇒True

32. Coherent sources emit waves with a constant phase difference that remains stable over time.

⇒ True

33. The visibility of interference fringes decreases as the coherence length of the light source increases.

⇒ False

34. The resolving power of an optical instrument increases with the decrease in the wavelength of light used.

⇒ True.

35. Diffraction is the bending of light waves as they pass through an aperture or around obstacles in their path.

⇒ True

36. Light waves can be polarized by scattering off particles in the atmosphere, leading to the blue color of the sky.

⇒ True

37. The fringes in Young's double-slit experiment become narrower when the distance between the slits increases.

⇒ False

❻ Very short type question [2 marks of each]

38. **Explain Huygen's principle.** **[PYQ Oct 2022]**

Answer: Huygen's principle states that every point on the wavefront may be considered a source of secondary spherical wavelets which spread out in the forward direction at the speed of light. The new wavefront is the tangential surface to all these secondary wavelets. Thus, it is a geometrical method to find the wavelength.

39. **Define diffraction and provide an example.**

Answer: Diffraction is the bending of waves as they encounter obstacles or pass through small openings. An example is the bending of light waves as they pass through a narrow slit or aperture.

40. State the conditions which must be satisfied for two light sources to be coherent.

Answer: For two light sources to be considered coherent, they must satisfy the following conditions:

a) Constant phase difference
b) Constant frequency
c) Constant amplitude
d) Spatial coherence

41. Explain why diffraction is a very common phenomenon in case of sound, but not that common in case of light. [Sample paper]

Answer: The reason for the diffraction of sound waves being more evident in daily experience than light waves is that sound waves have much higher wavelength compared to the visible light waves. For diffraction to occur, the slit width should be comparable to the wavelength of the light or sound waves. This condition is satisfied only for sound waves in everyday life. Thus sound diffraction is prominent.

42. How can one distinguish between an unpolarised and linearly polarised light beam using a polaroid? [CBSE Delhi 2019]

Answer: When an unpolarized light beam passes through a polaroid, it will become partially polarized. In contrast, when a linearly polarized light beam passes through a polaroid, its behavior depends on the alignment of the polarization axis of the polaroid with the polarization direction of the incoming light.

43. Why are coherent sources necessary to produce a sustained interference pattern? [Sample paper]

Answer:

1. Light waves having the same frequency, wavelength, and phase, or a constant phase difference, are emitted by a coherent source.
2. Two sources of light waves with the same frequency or wavelength, as well as a constant phase difference, are required to see an interference pattern.

3. If the sources are not coherent, they cannot emit waves continuously.
4. As a result, a coherent source can produce such a type of light wave.

44. The angle of maximum polarisation for a certain medium is 60°. Calculate the refractive index of the medium. **[sample paper]**

Answer: Relation between refractive index of medium and polarising angle is given by

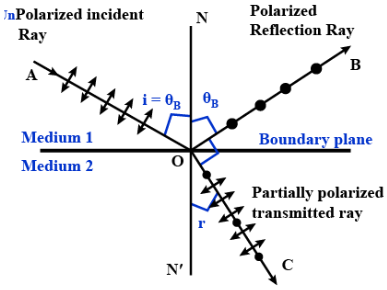
$\mu = \tan i_p$

Given: Polarising angle $i_p = 60°$

So, refractive inedx $\mu = \tan(60°) = 1.732$

45. State and explain Brewster's law with the help of a diagram. The value of Brewster angle for a transparent medium is different for light of different colours. Give reason. **[sample paper]**

Answer: Brewster's Law: It states that when light is incident at polarizing angle at the interface of a refracting medium, the refractive index of the medium is equal to the tangent of the polarising angle.



As Brewster angle depends on the refractive index and wavelength, so it is different for different colours.

46. How does the angular separation of interference fringes change in Young's experiment, if the distance between the slits is increased?

Answer: Angular separation, $\theta = \dfrac{\lambda}{d} \quad \therefore \theta \propto \dfrac{1}{d}$

When separation between two slits is increased, angular separation decreases.

47. State the reason, why two independent sources of light cannot be considered as coherent sources.

Answer: Two independent sources of light cannot be coherent. This is because light is emitted by individual atoms, when they return to ground state. Even the smallest source of light contains billions of atoms which obviously cannot emit light waves in the same phase.

48. State the reason, why two independent sources of light cannot be considered as coherent sources.

Answer: Two independent sources of light cannot be coherent. This is because light is emitted by individual atoms, when they return to ground state. Even the smallest source of light contains billions of atoms which obviously cannot emit light waves in the same phase.

❼ Short type question [3 marks of each]

49. Monochromatic light of wavelength λ = 450 nm illuminates the two slits of young's experiment having separation 0.15mm. The screen is placed at a distance of 1.0m from the slits. Find the separation of second bright fringe from the seventh dark fringe on the screen. [PYQ Jan 2021]

Answer:

Given: $\lambda = 450\text{ nm} = 450 \times 10^{-9}$ m, L = 1 m, d = 0.15 mm = 0.15×10^{-3}

Using formula: $\Delta y = \frac{\lambda L}{d}$

$$\Rightarrow \Delta y = \frac{450\times10^{9}\times1}{0.15\times10^{-3}} = \frac{3\times10^{-3}}{0.15}$$

$$\Rightarrow \Delta y = 20 \times 10^{-3} = 20\text{mm}$$

So, the separation between the second bright fringe and the seventh dark fringe on the screen is 20 mm.

50. A parallel beam of light of 600 nm falls on a narrow slit and the resulting diffraction pattern is observed on a screen 1.2 m away. It is observed that the first minimum is at a distance of 3 mm from the centre of the screen. Calculate the width of the slit. (All India 2013)

Answer:

$\lambda = 600 \text{ nm} = 600 \times 10^{-9} \text{ m}, \quad D = 1.2 \text{ m}$

First minima at $x_1 = 3 \text{ mm} = 3 \times 10^{-3} \text{ m}$

Diffraction angle for first minima :

$$\theta_1 = \frac{x_1}{D}$$

$$\theta_1 = \frac{3 \times 10^{-3} \times 10}{12} = 2.5 \times 10^{-3} \text{ rad}$$

We know, $a \sin \theta_1 = n\lambda, \qquad n = 1$

$a \sin \theta_1 = n\lambda$

Since angle is very small so $\sin \theta_1 \sim \theta$

$$a = \frac{\lambda}{\theta_1} = \frac{600 \times 10^{-9}}{2.5 \times 10^{-3}}$$

$$a = \frac{6}{2.5} \times 10^{-4} \text{ m} = 2.4 \times 10^{-4} \text{ m} = 0.24 \text{ mm}$$

$$\therefore \boxed{a = 0.24 \text{ mm}}$$

51. Answer the following questions:

(i) In what way is diffraction from each slit related to the interference pattern in a double slit experiment?

(ii) When a tiny circular obstacle is placed in the path of light from a distance source, a bright spot is seen at the centre of the shadow of the obstacle. Explain, why.

Answer:

(i) Diffraction from each slit is related to interference pattern in a double slit experiment in the following ways :

The intensity of minima for diffraction is never zero, while for interference it is generally zero.

All bright fringes for diffraction are not of uniform intensity, while for interference, these are of uniform intensity

(ii) Waves from the distant source are diffracted by the edge of the circular obstacle and these diffracted waves interfere constructively at the centre of the obstacle’s shadow producing a bright spot.

❽ Long type question [4 marks of each]

52. **If one of the two identical slits in young's double slit experiment is covered with a glass plate so that the intensity of light passing through it is reduced to 50%. Calculate the ratio of maximum to minimum intensity in interference fringes.** **[PYQ Jan 2021]**

Answer: Let the intensity through one of the slit be $I_1 = I$

So, intensity of light through the slit covered by glass = $I_2 = 0.5I$

Maximum intensity $I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$

$$\Rightarrow I_{max} = \left(\sqrt{I} + \sqrt{0.5I}\right)^2$$

$$\Rightarrow I_{max} = 2.9\ I$$

Minimum intensity $I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$

$$\Rightarrow I_{min} = \left(\sqrt{I} - \sqrt{0.5I}\right)^2$$

$$\Rightarrow I_{min} = 0.086\ I$$

Thus ratio of intensities $\frac{I_{max}}{I_{min}} = \frac{2.9\ I}{0.086\ I} = 33.8$

53. **Write the distinguishing features between a diffraction pattern due to a single slit and the interference fringes produced in Young's double-slit experiment?**

Answer:

Diffraction due to a Single Slit:

a) It is produced due to different parts of same wavefronts.
b) Central fringe is twice as wide as other fringes
c) Intensity of fringes decreases as we go to successive maxima away from the centre.
d) At an angle λ/a first minima is obtained.

Interference Fringe Young's Double Slit:

a) It is produced due to two different wavefronts.
b) Fringe width is of same size.
c) Fringes have same intensity.
d) At an angle λ/a maxima is object.

54. What is meant by coherent sources of light? Why are coherent sources required to show interference of light? Give one example of interference of light from daily life? [PYQ Jan 2021]

Answer:

Coherent Sources: Two sources giving light waves of same frequency and zero or constant initial phase are called coherent sources.

Necessity coherent sources to produce interference of light: Intensity at any point in cos f the region of superposition is $I = a_1^2 + a_2^2 + 2a_1a_2 \cos f$

If the interfering sources are not coherent then the phase difference at any point in the region of superposition will go on changing with time.

Then we shall get time-averaged intensity which is equal to $I = a_1^2 + a_2^2$ i.e., sum of intensities of individual waves.

This means that there will be no modifications in intensity in the region of superposition and hence no interference will be observed

Example of Interference in Daily Life: The bubbles of colorless soap solution appear coloured in white light. This is due to interference of white light rays reflected from upper and lower surface of soap film.

The colours of soap solution observed are those which satisfy the condition of maxima in reflected light.

55. (a) Write the conditions under which light sources can be said to be coherent.

(b) Why is it necessary to have coherent sources in order to produce an interference pattern? [All India 2013]

Answer:

(a) When two light sources produce waves having the same frequency and have a constant phase difference with time, they are called to be coherent.

The two conditions for two light sources to be coherent are as follows:

1. The coherent sources of light must have originated from a single source and must be monochromatic (that is they have a single wavelength) in nature.
2. The path difference between the light waves from the two sources must be small.

(b) Light waves having the same frequency, wavelength, and phase, or a constant phase difference, are emitted by a coherent source.

Two sources of light waves with the same frequency or wavelength, as well as a constant phase difference, are required to see an interference pattern. If the sources are not coherent, they cannot emit waves continuously. As a result, a coherent source can produce such a type of light wave.

❾ Very long type question [5 marks of each]

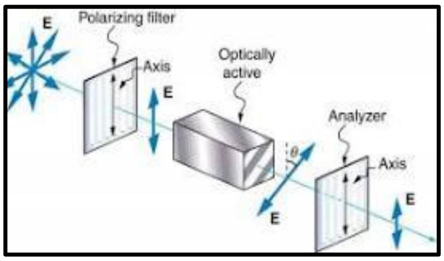
56. (a) Explain the phenomenon of polarisation of light. Draw a schematic arrangement of apparatus used for it.

(b) How unpolarised light is plane polarised by reflection from a transparent material? Show it by drawing a ray diagram.

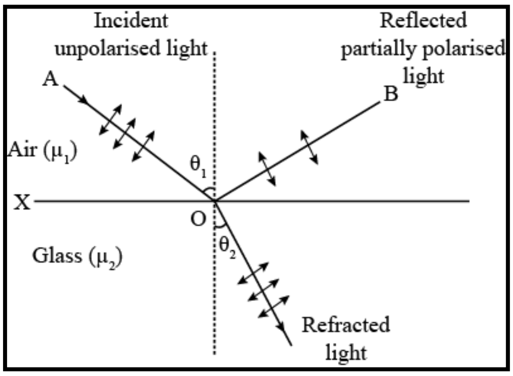
(c) Derive an expression for Brewster's law. **[PYQ Oct 2021]**

Answer: (a) The phenomenon of polarization of light refers to the process by which the oscillations of light waves become restricted to a specific orientation. Light waves are electromagnetic waves composed of electric and magnetic fields oscillating perpendicular to each other and perpendicular to the direction of wave propagation. When light is unpolarized, the electric field vectors vibrate in all possible directions perpendicular to the direction of propagation.

Schematic arrangement of apparatus used for it:



(b) Following figure shows the polarisation of light by reflection from a transparent glass surface:


Incident unpolarised light
Reflected partially polarised light
A
B
Air (μ_1)
θ_1
X
O
Glass (μ_2)
θ_2
Refracted light

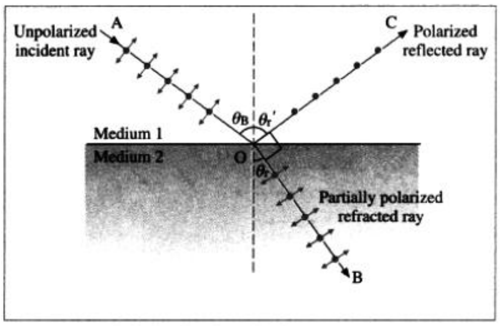
(c) Brewster's law: The tangent of the polarizing angle is equal to the refractive index of the reflecting medium with respect to the surrounding (${}_1n_2$). If θ_B is the polarizing angle,

$$\tan \theta_B = {}_1n_2 = \frac{n_2}{n_1}$$

Here n_1 is the absolute refractive index of the surrounding and n_2 is that of the reflecting medium. The angle θ_B is called the Brewster angle.

Consider a ray of unpolarized monochromatic light incident at an angle θ_B on a boundary between two transparent media as shown in below figure. Medium 1 is a rarer medium with refractive index n_1 and medium 2 is a denser medium with refractive index n_2.

Part of incident light gets refracted and the rest gets reflected. The degree of polarization of the reflected ray varies with the angle of incidence.


Unpolarized incident ray
A
C
Polarized reflected ray
θ_B
θ_r'
Medium 1
Medium 2
O
θ_r
Partially polarized refracted ray
B

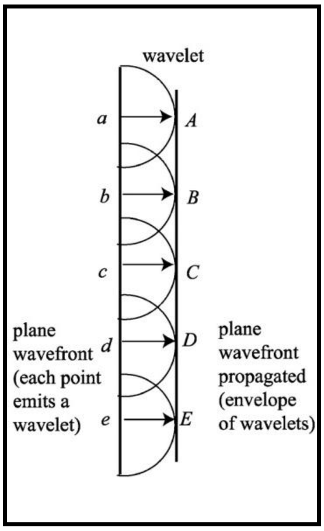
Polarization by reflection

57. (a) what is mean by a wave front? Mention the direction of a beam of light, with respect to the associated wavefront.

(b) With the help of a suitable diagram, explain the huygen's principle for the propagation of wavefront. How is a plane wave front produced?

Answer: **(a)** A Wavefront is defined as the locus of points that are in the same phase (a line or a surface) for a wave propagating by a source of the disturbance.
Wavefronts are always perpendicular to rays of light.
For a point far away from the source of the light wavefront is planar in shape as rays are parallel to each other.

(b) Huygens' principle states that every point on a wavefront acts as a point source of spherical secondary wavelets, and the new wavefront at any later time is the envelope of these secondary wavelets. This principle helps explain the behavior of waves, including light and sound, as they propagate through a medium.


wavelet
a
A
b
B
c
C
d
D
e
E
plane wavefront (each point emits a wavelet)
plane wavefront propagated (envelope of wavelets)

This diagram illustrates how Huygens' principle describes the propagation of wave fronts by considering the contribution of every point on the wavefront to the formation of the next wavefront.

58. **Find an expression for the intensity of transmitted light when a polaroid sheet is rotated between two crossed polaroids. In which position of the polaroid sheet will the transmitted Intensity be maximum?**

Answer: Let I_0 be the intensity of unpolarised light, incident on first polaroid , intensity of light transmitted from first Polaroid will be ,

$I_1 = I_0 \cos^2\theta,$

Or $I_1 = I_0 \times \frac{1}{2} = \frac{I_0}{2}$ .... (1)

Let θ be the angle between the transmission axes of the first and second polaroid (which is placed between two crossed polaroids) and ϕ be the angle between second and third polaroid,

Then $\theta + \phi = 90$ (as first and third polaroids are perpendicular to each other) ,

or $\varphi = 90 - \theta$,

Now intensity of light, transmitted from second polaroid,

$I_2 = I_1 \cos^2\theta = (I_0/2)\cos^2\theta$,

And intensity of light, transmitted from third polaroiod

$I_3 = I_2 \cos^2\phi = (I_0/2)\cos^2\theta \times \cos^2\phi$,
$I_3 = (I_0/2)\cos^2\theta \times \cos^2(90 - \theta)$,
or $I_3 = (I_0/2)\cos^2\theta \sin^2\theta$,
or $I_3 = (I_0/2)\cos^2\theta \sin^2\theta$,
or $I_3 = (I_0/2)(\sin^2 2\theta/4)$
this is the required expression .
Now I_3 will be maximum when $\sin 2\theta$ is
maximum i.e. $\sin 2\theta = 1 = \sin 90$,
or $2\theta = 90$,
or $\theta = 45^o$

24

Structure of atoms

Short summary

What do we learn

Quick Revision

➢ Introduction

"Atomic structure is the branch of physics in which we study about the atoms and its property."

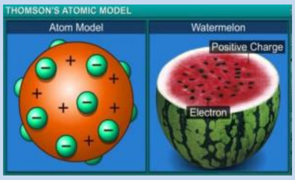
There are following three structures which tell us about the atom –:

1. Thomson atomic model
2. Rutherford atomic structure
3. Bohr's atomic model

➢ Thomson's atomic model

In 1898, J.J. Thomsan proposed that 'an atom is a sphere of +ve charged matter with electrons embedded in it'.

- This is also known as plum pudding model.
- Structure of atom is just like a watermelon or plum pudding.
- Electrons embedded all over the volume and +ve charge is spread over the volume.
- So, atoms are electrically neutral.


THOMSON'S ATOMIC MODEL
Atom Model
Watermelon
Positive Charge
Electron

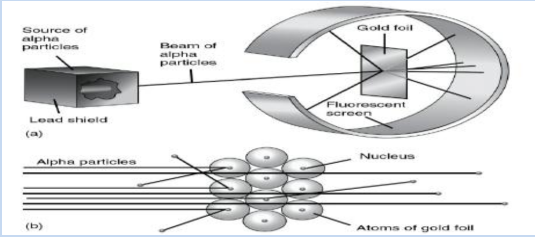
➢ Drawback of Thomson's model

1. It could not explain the origin of several **spectral series** in the case of hydrogen and other atoms.

2. It failed to explain the large angle **scattering of α particles** in Rutherford's experiment.

➢ Rutherford's experiment

In 1911, Rutherford performed an experiment with help of α **– particle**, **gold foil** and **ZnS** coated boundary. This experiment is known as α – scattering experiment.

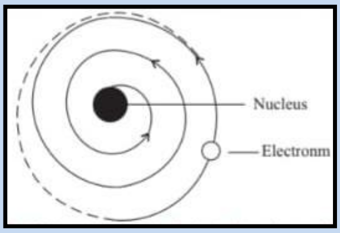

Source of alpha particles
Beam of alpha particles
Gold foil
Lead shield
Fluorescent screen
(a)
Alpha particles
Nucleus
(b)
Atoms of gold foil

∗ Observations from this experiment

1. Most of the α – particles pass through the gold foil undeflected or suffer small deviation.
2. A few α – particles deviate about 90° or more about 1 in 8000.
3. Occasionally an α – particle gets rebended from gold foil, suffering a deflection of nearly about 180° about 1 in 10^6.

➢ Rutherford’s atomic model

- An atom consists of a small and massive central core in which the entire positive charge and whole mass of atom are concentrated this core is called ‘Nucleus’.
- The size of nucleus is (10^{-15}m) very small as compared to size of atom (10^{-10}m).



- Nucleus is surrounded by a suitable member of electrons so that their negative charge is equal to positive charge on nucleus and the atom is electrical neutral.
- The electron revolves around the nucleus in various orbital.
- The centripetal force required for their revolution is provided by electrostatic attraction between the electrons and the nucleus.

➢ Impact perimeter

The perpendicular distance of the velocity vector of the α – particle from the centre of nucleus when it is far away from the atom.

$$\mathbf{b} = \frac{Ze^2 \cot\frac{\theta}{2}}{\frac{1}{2}mv^2}$$

➢ Drawback of Rutherford’s model

1. According to electromagnetic theory, an accelerated charged particle must radiate EM energy.

2. Rutherford model cannot explain the stability of atom.

3. As the electrons spiral inward, their angular frequency and velocity would change continuously and so the frequency of emitted light will also change.
They will emit a continuous spectrum instead of the actually observed spectrum.

➢ Distance of closest approach

At a certain distance r_0 from the nucleus, the α – particle stops for a moment and then begins to retrace its path (it is scattered to an angle of 180°).

The distance r_0 is called **Distance of closest approach**.

$$r_0 = \frac{2KZe^2}{KE_\alpha} = \frac{4KZe^2}{m_\alpha v^2}$$

Bohr's theory of Hydrogen atom

Bohr combined classical and early quantum concepts and gave his theory in the form of three postulates. These are –:

(i) first postulate: it states that an electron in an atom could revolve in certain stable orbits without the emission of radiant energy, contrary to the predictions of electromagnetic theory.

(ii)second postulate: This postulate states that the electron revolves around the nucleus only in those orbits for which the angular momentum is some integral multiple of h/2π.

where h = Planck's constant = 6.6×10^{-34} J – s

Angular momentum (L) of the orbiting electron is quantised, $\Rightarrow L = nh/2\pi$

Angular momentum of e^- = (L) = mvr

∴ For any permitted (stationary) orbit,

$$\boxed{mvr = nh/2\pi}$$

where, n = 1, 2, 3, ….

(iii)Third postulate: It states that an electron might make a transition from one of its specified non-radiating orbits to another of lower energy. A photon is emitted having energy equal to the energy difference between the initial and final states.

The frequency of the emitted photon is then given by $h_\nu = E_i - E_f$ $(E_i > E_f)$.

Bohr's radius

The radius of innermost orbit of the hydrogen atom is called Bohr's radius denoted by r_0.

Z = 1, n = 1

$$\boxed{r_0 = \frac{h^2}{4\pi^2 mke^2}}$$

NOTE: All are constant, therefore value of Bohr's radius = $\mathbf{r_0 = 0.53Å}$.

General formula of speed of electron in orbit

$$\boxed{v = \frac{2\pi kZe^2}{nh}}$$

Energy of electron

Total energy of electron = E_n

$$\boxed{E_n = \frac{-kZe^2}{2r}}$$

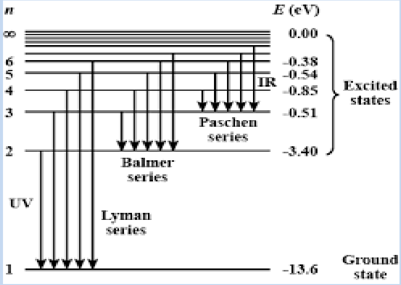
NOTE: The energy in an orbit is negative, which implies that the electron is bound to the nucleus.

Limitations of Bohr's model

1. Applicable only for hydrogen like atom.
2. Does not explain the fine structure of spectral lines in H-atom.
3. Does not explain about shape of orbit.

➢ *Hydrogen's spectrum*

Let us about the series of hydrogen spectrum.



General formula of frequency

$$v = \frac{R}{h}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

1. Lyman series ~ ultraviolet region

Lyman series was discovered by in 1906. According to Bohr, this series arises when an electron jumps to the first orbit ($n_1 = 1$) from an higher orbit ($n_2 = 2, 3, 4...$).

- **$n_1 = 1$, $n_2 = 2,3,4,......$**
- The frequencies of various spectral lines of this series are given by:

$$v = \frac{R}{h}\left[\frac{1}{1^2} - \frac{1}{n_2^2}\right]$$

5. Balmer series ~ visible range

- **$n_1 = 2$, $n_2 = 3,4,5,......$**

$$v = \frac{R}{h}\left[\frac{1}{2^2} - \frac{1}{n_2^2}\right]$$

2. Paschen's series ~ infra - red range

- **$n_1 = 3$, $n_2 = 4,5,6,......$**

$$v = \frac{R}{h}\left[\frac{1}{3^2} - \frac{1}{n_2^2}\right]$$

3. Bracket's series ~ mid infra - red range

- **$n_1 = 4$, $n_2 = 5,6,7,......$**

$$v = \frac{R}{h}\left[\frac{1}{4^2} - \frac{1}{n_2^2}\right]$$

4. Pffund series ~ far infra - red range

- **$n_1 = 5$, $n_2 = 6,7,8,......$**

$$v = \frac{R}{h}\left[\frac{1}{5^2} - \frac{1}{n_2^2}\right]$$

∗ Point to be noted:

1. For shortest wavelength (highest energy) put $n_i = \infty$. For example, for Balmer series of shortest wavelength $n_i = \infty$ and $n_f = 2$.

2. For longest wavelength of Balmer series H_α, put $n_i = 3$ and $n_f = 2$.

3. H_α line corresponds $n_i = 5$ and $n_f = 2$.

➢ *Energy level diagram of hydrogen*

$$E_n = \frac{2\pi^2 mk^2 Z^2 e^4}{h^2} \times \frac{1}{n^2}$$

$E_1 = -13.6$ v, $E_2 = -3.4$ ev, $E_3 = -1.5$ ev,

$E_4 = -0.85$ ev, $E_5 = -0.54$ev, $E_6 = -0.38$ev

$E_\infty = 0$

Clearly ***"an electron can have only certain definite values of energy while revolving in different orbits, this is called energy quantization"***.
n = 1 → ground state
n = 2 → 1st excited state
n = 3 → 2nd excited state

➢ *Excitation energy*

The energy required by its electron to jump out from ground state to any one of excited state.

1st excitation energy of H
$= E_2 - E_1 = -3.4\text{ev} - (-13.6) = 10.2$ ev
2nd excitation energy of H
$= E_3 - E_2 = 2.09$ ev

➢ *Ionization energy*

The energy required to take an electron from its ground state to outermost orbit ($n = \infty$).
Ionization energy of H
$= E_\infty - E_1 = 0 - (-13.6) = 13.6$ ev.

➢ *X - rays*

"X – rays are produced when fast moving electrons are suddenly stopped by a heavy metal in a glass tube having extremely low pressure."

∗ Properties of X – rays

X –rays show the following properties:
1. They affect the photographic plate.
2. They cause fluorescence in certain chemical compounds.
3. They ionize the gases.
4. They show no reflection in mirrors, no refraction in glass, no diffraction but when refined techniques are used they show all these familiar phenomena of light.
5. They do not get deviated by electric or magnetic field.

∗ X– Rays Spectra: The element whose X – ray spectra is studied is placed at the place of target of the X–rays tube. The X–ray wavelengths are determined by the **Bragg's spectrometer**.

➢ *Types of X - rays*

There are two types of x – rays:

❶ continuous X – rays

❷ characteristics X – rays

Question - answer

① MCQs

1. What did Rutherford’s alpha particle experiment prove?
   (a) Electrons (b) Protons (c) Neutrons (d) Nucleus

Answer: (d) Nucleus

2. Why was Rutherford’s atomic model unstable?
   (a) Electrons do not remain in orbit.
   (b) Nuclei will break down.
   (c) The nucleus repels electrons.
   (d) Orbiting electrons radiate energy.

Answer: (a) Electrons do not remain in orbit.

3. Balmer series lies in which spectrum?
   (a) Ultraviolet (b) Visible (c) Infrared (d) Partially Visible

Answer: (b) Visible

4. According to the classical theory, the circular path of the electrons is:
   (a) Circular (b) Parabolic (c) Spiral (d) Straight line

Answer: (c) Spiral

5. Electrons in the atom are held to the nucleus by:
   (a) Nuclear Force (b) Coulomb’s Force
   (c) Gravitational Force (d) Van Der Waal’s Force

Answer: (b) Columb’s Force

6. The electrons of Rutherford’s model would be expected to lose energy because:
   (a) They jump on the nucleus
   (b) They move randomly
   (c) Radiate electromagnetic waves
   (d) Escape from the atom

Answer: **(c) Radiate electromagnetic waves.**

7. Who discovered the first spectral series?
   (a) Lyman (b) Balmer (c) Paschen (d) Pfund

Answer: **(b) Balmer**

8. Which of the following did Bohr use to explain his theory?
   (a) Quantization of angular momentum
   (b) Conservation of Quantum frequency
   (c) Conservation of Mass
   (d) Conservation of Linear Momentum

Answer: **(a) Quantization of angular momentum**

9. The significant result deduced from Rutherford's scattering experiment is that:
   (a) the whole of the positive charge is concentrated at the centre of an atom
   (b) there are neutrons inside the nucleus
   (c) α-particles are hydrogen nuclei
   (d) electrons are embedded in the atom

Answer: **(a) the whole of the positive charge is concentrated at the centre of an atom.**

10. The first model of the atom was proposed by:
    (a) Neils Bohr (b) Albert Einstein
    (c) J.J Thompson (d) Ernest Rutherford

Answer: **(c) J.J Thomson**

11. In an experiment of scattering of alpha particle showed for the first time that the atom has: **[sample paper]**
    (a) Electron (b) Proton (c) Neutron (d) Nucleus

Answer: **(d) Nucleus**

12. According to Bohr's postulates, an electrons revolve around the nucleus in ………. orbits. **[sample paper]**

(a) Dynamic (b) Stationary (c) Lower (d) First

Answer: **(b) Stationary**

13. Which spectral series of hydrogen lie in UV region? **[sample paper]** (a) Paschen (b) Lyman (c) Brackett (d) Balmer

Answer: **(b) Lyman**

14. The idea of nuclear model of atom was proposed by: **[PYQ NIOS Jan 2021]** (a) John Dalton (b) Lord Rutherford

(c) Niels Bohr (d) Linus Pauling

Answer: **(b) Lord Rutherford**

15. The number of neutrons in the nucleus of ${}^{27}_{13}\mathrm{Al}$ is: **[PYQ NIOS Jan 2021]** (a) 13 (b) 27 (c) 40 (d) 14

Answer: **(d) 14**

16. Which of the following spectral series falls within visible region of electromagnetic radiation? **[PYQ NIOS April 2021]**

(a) Lyman series (b) Balmer series

(c) Paschen series (d) Pfund series

Answer: **(b) Balmer series**

17. In Rutherford's scattering experiment, target nucleus was bombarded with: (a) α – particles (b) β – particles (c) γ – rays (d) protons

Answer: **(b) β – particles** **[PYQ NIOS April 2022]**

18. Who explained the splitting of special lines in magnetic field?

(a) Zeeman (b) Bohr (c) Summerfield (d) Einstein

Answer: **(a) Zeeman**

19. The transition of electron from n = 4, 5, 6, ……… to n = 3 corresponds to

(a) Lyman series (b) Balmer series

(c) Paschen series (d) Bracket series

Answer: (c) Paschen series

20. To explain his theory, Bohr used:

(a) conservation of linear momentum

(b) conservation of angular momentum

(c) conservation of quantum frequency

(d) conservation of energy

Answer: (b) conservation of angular momentum

21. Find the true statement.

(a) an electron will not lose energy when jumping from the 1st orbit to 3rd orbit

(b) an electron will not give energy when jumping from the 1st orbit to 3rd orbit

(c) an electron will release energy when jumping from the 1st orbit to 3rd orbit

(d) an electron will absorb energy when jumping from the 1st orbit to 3rd orbit

Answer: (d) an electron will absorb energy when jumping from the 1st orbit to 3rd orbit

22. The size of the atom is proportional to which of the following?

(a) A (b) $A^{1/3}$ (c) $A^{2/3}$ (d) $A^{-1/3}$

Answer: (b) $A^{1/3}$

23. The energy of characteristic X-ray is a consequence of which of the following?

(a) The energy of the projectile electron

(b) The thermal energy of the target

(c) Transition in target atoms

(d) Temperature

Answer: (c) Transition in target atoms.

24. Find out the minimum energy required to take out the only one electron from the ground state of Li^+?

(a) 13.6 eV (b) 122.4 eV (c) 25.3 eV (d) 67.9 eV

Answer: **(b) 122.4 eV**

25. In Geiger – marsden scattering experiment, the trajectory traced by an α – particle depends on

(a) Number of collision
(b) Number of scattered α – particles
(c) Impact perimeter
(d) None of these

Answer: **(c) Impact perimeter**

② complete the sentence using an appropriate word:

26. **Orbits, Sphere, visible, atomic, one**

1. According to Thomson's atomic model, an atom consists of a positively charged ……………… embedded with negatively charged electrons.
2. Bohr's atomic model proposes that electrons orbit the nucleus in discrete ……………… each corresponding to a specific energy level.
3. One of the limitations of Bohr's model is its inability to explain the spectral lines of atoms with more than ……………… electron(s).
4. The discovery of the atomic nucleus, as proposed by Rutherford, revolutionized the understanding of atomic structure and paved the way for modern ……………… theory.
5. Balmer series lies in ………………… Spectrum

Answer: **(1) sphere, (2) orbits (or shell), (3) one, (4) atomic, (5) visible**

③ Fill in the blanks:

27.

(a) Rutherford's alpha particle scattering experiment led to the discovery of the ………………

(b) Thomson's atomic model is often referred to as the "……………… pudding" model.

(c) Thomson's atomic model proposed that atoms consist of a **…………….** charged sphere embedded with negatively charged electrons.

(d) Bohr's atomic model introduced the concept of **……………** orbits, where electrons do not emit radiation.

(e) **…………….** spectral series of hydrogen lie in UV region

Answer: **(a) Atomic nucleus, (b) Plum, (c) positively, (d) stationary, (e) Lyman**

④ Match the following:

28. **Match column I statement with the right statement of column II.**

Column I	Column II
1. Plum pudding model	(a) Rutherford
2. Discovery of nucleus	(b) Thomson
3. Scattering of α – particles	(c) Bohr

Answer: **1 – (b), 2 – (c), 3 – (a)**

⑤ True or false :

29. Thomson's atomic model proposed that atoms consist of a positively charged nucleus surrounded by negatively charged electrons.

$\Rightarrow$ False.

30. According to Bohr's atomic model, electrons revolve around the nucleus in continuous orbits.

$\Rightarrow$ False.

31. Rutherford's alpha particle scattering experiment led to the discovery of the atomic nucleus.

$\Rightarrow$ True.

32. In Thomson's atomic model, electrons are distributed uniformly throughout the positively charged sphere.

$\Rightarrow$ True.

33. Bohr's atomic model successfully explained the line spectra of hydrogen atoms.

⇒True.

34. Rutherford's model of the atom proposed that electrons orbit the nucleus in circular paths.

⇒ False.

35. Thomson's atomic model is often referred to as the "plum pudding" model.

⇒ True.

36. According to Bohr's model, electrons emit or absorb energy when they transition between energy levels.

⇒ True.

37. Rutherford's alpha particle scattering experiment confirmed the existence of a dense, positively charged core within the atom.

⇒ True.

38. One limitation of Bohr's model is its inability to explain the stability of multi electron atoms.

⇒ True.

⑥ Very short type answer question [2 marks each]:

39. **State Thomson's atomic model?**

Answer: Thomson described the structure of an atom similar to a plum – pudding or watermelon. According to Thomson, the atom was a positively charged sphere with the electrons being embedded on the surface of the positively charged sphere.

40. **Write two postulates of Rutherford's atomic model?**

[PYQ NIOS April 2022]

Answer: The postulates of the Rutherford model of atom are:

- An atom has a center called the nucleus.
- Compared to the size of an atom the size of the nucleus is very small.

41. Define Ionization energy. What is its value for a hydrogen atom?

Answer: Ionization energy: The energy required to knock out an electron from an atom is called ionisation energy of the atom.

For hydrogen atom it is 13.6 eV.

42. Explain how the concept of quantization of angular momentum is related to Bohr's model of the atom.

Answer: In Bohr's model, electrons are restricted to certain quantized orbits around the nucleus. The quantization of angular momentum (L = nh/2π) ensures that only specific orbits are allowed for electrons, where 'n' is the principal quantum number. This concept explains why electrons do not spiral into the nucleus, as classical electromagnetic theory would predict.

43. Write the expression for Bohr's radius in hydrogen atom.

Answer: Bohr's radius in hydrogen atom,

$$r_1 = \frac{\varepsilon_0 h^2}{\pi m e^2} = \mathbf{0.5.29 \times 10^{-10}\ m}$$

44. What is the ratio of radii of the orbits corresponding to first excited state and ground state in a hydrogen atom? [Delhi 2010]

Answer:

Radius of Bohr's stationary orbits, $r = \dfrac{n^2 h}{4\pi^2 m K e^2}$

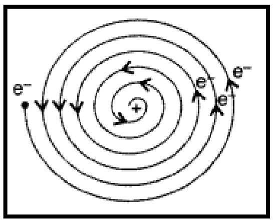
Clearly, $r \propto n^2$ and in ground state, $n = 1$

For 1st excited state, $n = 2$

$\therefore$ Ratio of radii of the orbits $= \dfrac{2^2}{1^2} = \dfrac{4}{1} = \mathbf{4:1}$

45. Why is the classical (Rutherford) model for an atom—of electron orbitting around the nucleus—not able to explain the atomic structure?

Answer: As the revolving electron loses energy continuously, it must spiral inwards and eventually fall into the nucleus. So it was not able to explain the atomic structure.



46. When an electron falls from a higher energy to a lower energy level, the difference in the energies appears in the form of electromagnetic radiation. Why can't it be emitted as other forms of energy?

Answer: The accelerated electron produces an electric as well as the magnetic field due to which the transition of an electron from a higher energy level to a lower energy level, the difference in the energy levels appears in the form of electromagnetic radiation.

47. Write two important limitations of Rutherford nuclear model of the atom.

Answer: ∗ **Important limitations of Rutherford Model:**

1. According to Rutherford model, electron orbiting around the nucleus, continuously radiates energy due to the acceleration; hence the atom will not remain stable.
2. As electron spirals inwards; its angular velocity and frequency change continuously; therefore it will emit a continuous spectrum.

48. Explain the significance of the Rydberg constant.

Answer: The Rydberg constant is a fundamental physical constant relating to the energy differences between the energy levels of an atom. It is used in the Rydberg formula to calculate the wavelength of light emitted or absorbed during electronic transitions in hydrogen-like atoms.

⑦ Short type question answer (3 marks of each)

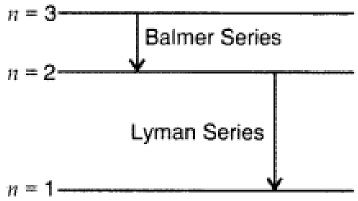
49. (i) In hydrogen atom, an electron undergoes transition from 2nd excited state to the first excited state and then to the ground state. Identify the spectral series to which these transitions belong.

(ii) Find out the ratio of the wavelengths of the emitted radiations in the two cases. [Comptt. All India 2012]

Answer:

(*i*) $n_f = 2,\quad n_i = 3$ *Balmer series*

$n_i = 2,\quad n_f = 1$ *Lyman series*



$$(ii)\quad \frac{1}{\lambda_B} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = R\left[\frac{1}{4} - \frac{1}{9}\right] = \frac{5}{36}R$$

$$\text{...where} \left[\begin{array}{l} \lambda_B \text{ is the wavelength for Balmer series.} \\ \lambda_L \text{ is the wavelength for Lyman series.} \end{array}\right.$$

$$\text{and}\quad \frac{1}{\lambda_L} = R\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = R\left[\frac{1}{1} - \frac{1}{4}\right] = \frac{3}{4}R$$

$$\therefore\ \frac{\lambda_B}{\lambda_L} = \frac{36}{5} \times \frac{3}{4} = \frac{27}{5}$$

$\therefore$ ***Ratio*** $= \lambda_B : \lambda_L = \mathbf{27 : 5}$

50. Calculate the shortest wavelength in the Balmer series of hydrogen atom. In which region (infra-red, visible, ultraviolet) of hydrogen spectrum does this wavelength lie? (All India 2012)

Answer:

In Balmer series, an electron jumps from higher orbits to the second stationary orbit ($n_f = 2$). Thus for this series:

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \text{ and in this case}$$

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n_i^2}\right)$$

R (Rydberg's constant) = $1.097 \times 10^7\ \text{m}^{-1}$

For the shortest wavelength, $n_i = \infty$;

Hence, $\frac{1}{\lambda} = \frac{R}{4}$

$$\text{or}\quad \lambda = \frac{4}{R} = \frac{4}{1.097 \times 10^7}\ \text{m}$$

$$= 3.646 \times 10^{-7}\ \text{m} = \mathbf{3646\ \text{Å}}$$

It will lie in ultra-violet region.

51. **Define the distance of closest approach. An α - particle of kinetic energy 'K' is bombarded on a thin gold foil. The distance of the closest approach is V. What will be the distance of closest approach for an α – particle of double the kinetic energy?** **[Delhi 2016]**

Answer:

The distance of closest approach is defined as "the distance of charged particle from the centre of the nucleus, at which the whole of the initial kinetic energy of the (far off) charged particle gets converted into the electric potential energy of the system".

Distance of closest approach (r_c) is given by

$$r_c = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2Ze^2}{K} \cdot$$

From this expression $r_c \propto \frac{1}{K}$

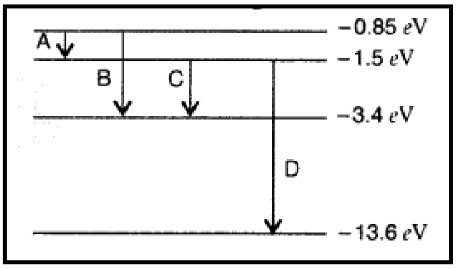
$\therefore$ **When 'K' is doubled, r_c becomes half.**

52. **What are the limitations of Bohr's Atomic Model?**

Answer: The limitations of Bohr's atomic model are mentioned below –

1. The Bohr atomic model theory considers electrons to have both a known radius and orbit that is known position and momentum at the same time which is impossible according to the Heisenberg uncertainty principle.
2. The Bohr atomic model theory made correct predictions for smaller-sized atoms like Hydrogen but poor spectral predictions are obtained when large atoms are considered.
3. It failed to explain the Zeeman Effect when the spectral line is split into several components in a magnetic field.
4. Bohr's Atomic Model theory failed to explain the stark effect when the spectral line gets split up into fine lines in the presence of an electric field.

53. **The energy level diagram of an element is given. Identify, by doing necessary calculations, which transition corresponds to the emission of a spectral line of wavelength 102.7 nm.** **[Delhi 2008]**



Answer:

Here $\lambda = 102.7$ nm $= 102.7 \times 10^{-9}$ m

The energy of the emitted photon is,

$$E = \frac{hC}{\lambda} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{102.7 \times 10^{-9}}$$

$$= \frac{19.878 \times 10^{-26}}{102.7 \times 10^{-9}} = 1.9355 \times 10^{-18} \text{ J}$$

$$\therefore \quad \text{Energy corresponds} = \frac{1.9355 \times 10^{-18}}{1.6 \times 10^{-19}} \text{ eV}$$

$$= 12.097 \text{ eV} \approx \mathbf{12.1\ eV}$$

This energy corresponds to the transition D for which the energy change

$$= -1.5 - (-13.6) = 12.1 \text{ eV}$$

54.

(a) The radius of the innermost electron orbit of a hydrogen atom is 5.3 × 10^{-11} m. Calculate its radius in n = 3 orbit.

(b) The total energy of an electron in the first excited state of the hydrogen atom is -3.4 eV. Find out its: (i) kinetic energy and (ii) potential energy in this state. **[Comptt. Delhi 2014]**

Answer:

(*a*) Radius of orbit, $r_n = n^2 r_0$

where [r_0 (Bohr's radius) $= 5.3 \times 10^{-11}$ m, $n = 3$

$\therefore \quad r_3 = (3)^2 \times 5.3 \times 10^{-11}$ m

$= 47.7 \times 10^{-11}$ m $= \mathbf{4.77 \times 10^{-10}\ m}$

(*b*) (*i*) Kinetic energy = – (Total energy)

$= -(-3.4 \text{ eV}) = \mathbf{+3.4\ eV}$

(*ii*) Potential energy = – 2 × Kinetic energy

$= -2 \times (3.4) = \mathbf{-6.8\ eV}$

55. **Define the distance of the closest approach. What will be the distance of the closest approach for an alpha particle if kinetic energy gets doubled?**

Answer: The distance of the closest approach is defined as "the distance of a charged particle from the centre of the nucleus at which the whole of the initial kinetic energy of the charged particle gets converted into the electric potential energy of the system.

Distance of the closest approach is given by: $r_c = \frac{1}{4\pi\epsilon_0} \times \frac{2Ze^2}{K}$

From this expression $r_c \propto \frac{1}{K}$

Therefore, When K is doubled, r_c becomes half.

⑧Long type answer question:

56. Using Bohr's postulates of the atomic model, derive the expression for radius of nth electron orbit. Hence obtain the expression for Bohr's radius.

[All India 2012]

Answer: Basic postulates of Bohr's atomic model:

(i) Every atom consists of a central core called nucleus in which entire positive charge and mass of the atom are concentrated. A suitable number of electrons revolve around the nucleus in circular orbit. The centripetal force required for revolution is provided by the electrostatic force of attraction between the electron and the nucleus.

(ii) Electron can resolve only in certain discrete non-radiating orbits, called stationary orbit. Total angular momentum of the revolving electron in an integral multiple of h/2π.

$mvr = \frac{nh}{2\pi}$ … where [h is plank constant]

(iii) The radiation of energy occurs only when an electron jumps from one permitted orbit to another. The difference in the total energy of electron in the two permitted orbit is absorbed when the electron jumps from inner to the outer orbit and emitted when electron jumps from outer to inner orbit.

According to Bohr’s postulates, angular momentum of electron for any permitted orbit is,

$$mvr = \frac{nh}{2\pi} \qquad \text{or} \qquad v = \frac{nh}{2\pi mr} \qquad \ldots(i)$$

Also, according to Bohr’s postulates, the centripetal force is equal to electrostatic force between the electron and nucleus.

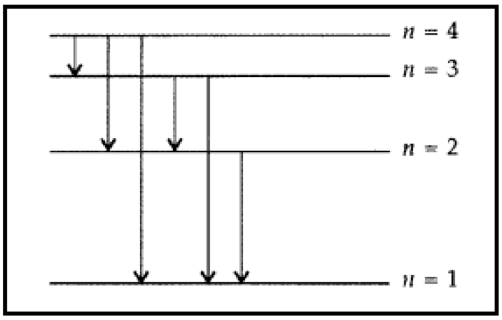
$$\frac{mv^2}{r} = K\frac{Ze\cdot e}{r^2} \qquad \text{or} \qquad \frac{m}{r}\cdot\frac{n^2h^2}{4\pi^2m^2r^2} = \frac{KZe^2}{r^2}$$

$$\text{or} \quad r\cdot 4\pi^2 mKZe^2 = n^2h^2 \quad \therefore \boxed{r = \frac{n^2h^2}{4\pi^2 mKZe^2}} \qquad \ldots(ii)$$

$$r = \frac{h^2}{4\pi mke^2}$$

It is the expression for Bohr’s radius, which is equal to 0.5 Å. For first orbit of hydrogen atom, n = 1, Z = 1 then we have r = 0.529 Å

57. **The figure shows energy level diagram of hydogen atom**



(a) Find out the transition which results in the emission of a photon of wavelength 496 nm.

(b) Which transition corresponds to the emission of radiation of maximum wavelength? Justify your answer. [Comptt. All India 2012]

Answer:

(a) Transition emitting wavelength λ = 496 nm The given wavelength lies in visible region (Balmer series) when,

$$n_1 = 2,\ n_2 = 4$$

$$\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) \qquad [R = 1.097 \times 10^7\ \text{m}^{-1}]$$

$$\frac{1}{\lambda} = 1.097\times10^7\left(\frac{1}{2^2} - \frac{1}{4^2}\right) = 1.097\times10^7\times\frac{3}{16}$$

$$\Rightarrow \quad \lambda = \frac{16}{3}\times\frac{10^{-7}}{1.097} = 486\ \text{nm} \approx 496\ \text{nm}$$

Hence the transition from $n_2 = 4$ to $n_1 = 2$

(b) Transition corresponding to emission of maximum wavelength,

$$E = h\nu = \frac{hc}{\lambda} \text{ or } E \propto \frac{1}{\lambda}$$

which means that the maximum wavelength emmission will be there when the energy level difference is minimum. From the given energy level diagram, it corresponds to: $n_2 = 4$ to $n_1 = 3$

58. Compare and contrast Thomson's model and Rutherford's model of the atom. Highlight the key differences and similarities.

Answer: Thomson proposed that atoms could be described as negative particles floating within a soup of diffused positive charges. This model is often called the plum pudding model of the atom since its description is very similar to plum pudding, a famous English dessert. Rutherford proposed the nuclear model, in which an atom consists of a tiny, positively charged nucleus surrounded by negatively charged electrons. Rutherford calculated that the nucleus took up a tiny fraction of the atom’s volume based on the number of alpha particles deflected in his experiment.

∗ **Key differences between Thomson and Rutherford’s atomic model –:**

Thomson’s atomic model	Rutherford’s atomic model
1. Electrons are embedded in a positively charges solid material with a spherical shape.	**(i)** An atom has a nucleus in its centre and electrons orbit around it.
2. The Thomson model of the atom does not include a description of nucleus.	**(ii)** The Rutherford model of the atom describes the nucleus of an atom and its location within the atom.
3. Electrons are embedded in a small material.	**(iii)** Electrons are located around the nucleus.
4. The orbitals of the atom are not represented.	**(iv)** The atom’s orbitas and electron positions are described
5. The mass of an atom is the mass of a positively charged solid containing electrons.	**(v)** The mass of an atom is concentrated in its nucleus.

∗ Similarities between Thomson and Rutherford's atomic model –:

- **Electrons:** Both models recognize the presence of electrons within the atom. In both models, electrons are depicted as negatively charged particles.
- **Charge Neutrality:** Both models maintain the overall neutrality of the atom. In Thomson's model, the positive charge distributed throughout the atom balances the negative charge of the electrons, while in Rutherford's model, the positive charge in the nucleus balances the negative charge of the electrons.

59. Describe Bohr's model of the hydrogen atom. How does it address the limitations of earlier atomic models?

Answer: Bohr's model of the hydrogen atom, proposed in 1913, was a significant advancement in atomic theory that addressed several limitations of earlier models, particularly those proposed by Thomson and Rutherford.

Here's a description of Bohr's model and how it tackled the shortcomings of earlier atomic models:

∗ Bohr's Model of the Hydrogen Atom:

- **Quantized Energy Levels:** Bohr introduced the concept of quantized energy levels for electrons within the atom. He proposed that electrons orbit the nucleus in specific, discrete energy levels without radiating energy. These energy levels are designated by quantum numbers, with each level corresponding to a specific energy state.
- **Stationary Orbits:** Bohr suggested that electrons revolve around the nucleus in circular orbits, much like planets orbiting the sun. However, unlike classical planetary motion, electrons are restricted to specific orbits without emitting radiation. These orbits, or stationary states, are stable and do not decay.
- **Energy Absorption and Emission:** According to Bohr's model, electrons can only transition between energy levels by absorbing or emitting discrete amounts of energy in the form of photons.

When an electron moves to a lower energy level, it emits a photon of specific frequency and energy corresponding to the energy difference between the initial and final states.

- **Angular Momentum Quantization:** Bohr postulated that the angular momentum of an electron in a particular orbit is quantized and is given by an integer multiple of Planck's constant divided by 2π. This quantization of angular momentum helped explain the stability of electron orbits and prevented the electron from spiraling into the nucleus, as predicted by classical electromagnetism.

∗ **Addressing Limitations of Earlier Models:**

- **Stability of Atoms:** Bohr's model provided a mechanism for the stability of atoms, which was lacking in earlier models. By quantizing the energy levels and angular momentum of electrons, Bohr explained why electrons do not continuously lose energy and spiral into the nucleus, as suggested by classical physics.
- **Spectral Lines of Hydrogen:** One of the significant successes of Bohr's model was its ability to accurately predict the spectral lines of hydrogen. By relating the energy differences between electron orbits to the frequencies of emitted or absorbed photons, Bohr derived the formula for the hydrogen spectral lines, which matched experimental observations.
- **Quantization of Energy:** Bohr's model introduced the concept of quantized energy levels, which reconciled the continuous spectra observed in blackbody radiation and the discrete spectral lines observed in atomic emission spectra. This addressed a key limitation of earlier atomic models that could not explain the quantized nature of atomic spectra.

Overall, Bohr's model of the hydrogen atom provided a framework for the development of quantum mechanics. It laid the foundation for further advancements in atomic theory and remains a cornerstone of modern physics.

60. Discuss the production and properties of X-rays. How are X-rays utilized in studying atomic structure and material properties?

Answer: X – rays are a form of electromagnetic radiation with wavelengths shorter than those of ultraviolet rays and longer than those of gamma rays.

∗ Production of X-rays:

1. **Bremsstrahlung Radiation:** When high-energy electrons are decelerated or deflected by a target material, they can emit X-rays through a process called bremsstrahlung radiation.

This occurs when electrons are accelerated towards the positively charged nucleus of an atom within the target material, causing them to lose kinetic energy and emit X-rays in the process.

2. **Characteristic X-rays:** When inner-shell electrons of atoms in the target material are ionized by collisions with high-energy electrons, outer-shell electrons can transition to fill the vacancies in the inner shells.

These transitions result in the emission of characteristic X-rays with energies specific to the elements present in the target material.

∗ Properties of X-rays:

1. **Penetration:** X-rays have high penetrating power and can pass through materials that are opaque to visible light. The ability of X-rays to penetrate materials depends on their energy and the density and composition of the material.
2. **Absorption:** The absorption of X-rays by a material depends on its thickness, density, and composition. Dense materials and materials with high atomic numbers tend to absorb X-rays more effectively.
3. **Diffraction:** X-rays can undergo diffraction when they interact with the crystalline structure of a material. This phenomenon allows X-ray diffraction (XRD) techniques to be used for analyzing the atomic and molecular structure of crystalline materials.

∗ Utilization in Studying Atomic Structure and Material Properties:

- **X-ray Crystallography:** X-ray crystallography is a powerful technique used to determine the atomic and molecular structure of crystalline materials. By analyzing the diffraction patterns produced when X-rays interact with the crystal lattice of a material, scientists can deduce the spatial arrangement of atoms within the crystal.
- **X-ray Spectroscopy:** X-ray spectroscopy techniques, such as X-ray photoelectron spectroscopy (XPS) and X-ray absorption spectroscopy (XAS), provide information about the electronic structure and chemical composition of materials. These techniques are valuable for studying the bonding interactions and oxidation states of atoms in a material.
- **Medical Imaging:** X-rays are widely used in medical imaging techniques such as X-ray radiography, computed tomography (CT), and fluoroscopy. These techniques allow healthcare professionals to visualize internal structures of the body, diagnose medical conditions, and monitor treatments.
- **Industrial Applications:** X-rays are employed in various industrial applications, including non-destructive testing (NDT) of materials for quality control and inspection purposes. X-ray imaging techniques are used to detect defects, cracks, and irregularities in manufactured components without damaging them.

25

Dual nature of radiation and matter

Short summary

What do we learn

Quick Revision

➢ Introduction

Dual nature means to the double nature or behavior of light.
We read many times that light has dual nature.

1. Wave nature
2. Particle nature

Light

Radiation (wave) → Particle nature (photon)

Matter (particle) → Wave nature

We have to study the particle nature of radiation and the wave nature of particle.

➢ Electron emission

The process of emission of electrons from the metal surface when a certain amount of energy is absorbed by the metal, is called electron emission.

A metal have free electrons, but these electrons cannot come out of the metal surface. It is because, the metal surface acquires +ve charge and the electron is pulled back into the metal. +ve charge of the metal attracted the electron moving out from surface.

➢ Work function

"The minimum amount of energy required to emit an electron from metal surface is called work function of that metal."

- This is denoted by $\O_0$ or W_0.
- Work function is measured in electron volt (ev).

Kinetic energy = Supply energy – Work function

$$\boxed{K.E. = E - \O_0}$$

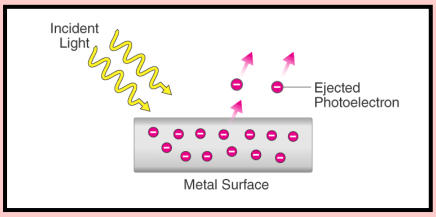
➢ Types of electron emission

There are 3 types of electron emission;

1. **Thermionic emission:** electrons emitted by the heating of metals.
2. **Field emission:** electrons emitted by the strong electric field.
3. **Photoelectric emission:** when light of suitable frequency incident on metal surface.

➢ Photoelectric effect

"The phenomenon of ejection of electrons from a metal surface when light of sufficient frequency falls upon it is known as 'Photoelectric Effect'."



- The ejected electron is called **Photo electrons**.

According to plank's Quantum theory, the light moves in the form of small bundles or packets called **Photons.**

$$\boxed{E = h\nu = h\frac{c}{\lambda}}$$

Where:
E = energy of photon, h = plank's constant, ν = frequency, c = speed of light, λ = wavelength

- Unit of plank's constant: Js, JHz^{-1} and evs.

➢ Rest mass and kinetic mass

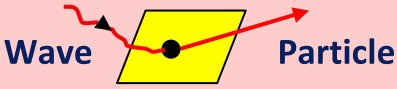
Photon is not a material particle. So its rest mass is zero but it has kinetic mass.

$$\boxed{m = \frac{h}{c\lambda} = \frac{h\nu}{c^2}}$$

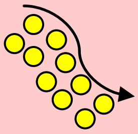
Momentum of photon (P):

$$\boxed{P = mv = \frac{h}{\lambda} = \frac{h\nu}{c}}$$

➢ Points to be noted

1. Rest mass of photon is zero.
2. Photon is neutral particle, when it passes through electric or magnetic field then force on it is zero.
3. 

4. In any particular frequency, energy of photon same.



5. If frequency increases then energy of each and every photon is increases and also the energy of light increases.
6. If intensity increases the number of photon is increases and also the energy of light increases.

➢ Threshold frequency and threshold wavelength

- The minimum frequency of incident light which is just capable to ejecting electrons from a metal surface is called the **threshold frequency (ν_0)**.

Work function = Planck's constant × threshold frequency

- The wavelength of light related to threshold frequency is known as **threshold wavelength (λ_0)**.

$$\boxed{W_0 = h\nu_0 = \frac{hc}{\lambda_0}}$$

Einstein's photoelectric equation

According to Einstein ***"the emission of a photoelectron is the result of the interaction of a single photon with single electron which is completely observed by electron"***.

$(K.E.)_{max}$ = energy of photon – work function

$$\Rightarrow \boxed{(K.E.)_{max} = h\nu - w_0}$$

$$\Rightarrow \boxed{(K.E.)_{max} = h\nu - h\nu_0 = h(\nu - \nu_0)}$$

Or

$$\boxed{\frac{1}{2} m_e V_{max}^2 = h(\nu - \nu_0) = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)}$$

Stopping potential

"The maximum retarding potential applied to anode of a photoelectric tube which is just capable to stopping photoelectric current is called stopping potential (V_0)."

$$(K.E.)_{max} = eV_0$$

$$\Rightarrow \boxed{eV_0 = h(\nu - \nu_0)}$$

$$\Rightarrow \boxed{eV_0 = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}}$$

$$\Rightarrow \boxed{V_0 = \left(\frac{h}{e}\right)\nu - \left(\frac{h\nu_0}{e}\right)}$$

$$\Downarrow$$

$$y = mx - c$$

Law of photoelectric emission

(i) The emission of photoelectrons take place only when the frequency of incident radiation is above a certain critical value called Threshold frequency.

(ii) The emission of photoelectrons takes place as soon as light falls on metal surface (in nearly 10^{-9}).

(iii) The number of photoelectrons emitted from a metal surface depends only on the intensity of the incident light not on the frequency.

(iv) The maximum kinetic energy of photoelectrons depends only on frequency not on intensity.

Effect on photoelectric emission

1. Effect of Frequency: If frequency increases then negative stopping potential also increases but not any effect on electric current.

2. Effect of Intensity: If intensity increases then current in photoelectric tube also increases.

3. Effect of Potential: it is observed that at high intensity, the value of saturation current increases.

➢ Applications of photoelectric cell

1. Reproduction of sound in cinematography (motion pictures)
2. Transmitting pictures over large distances
3. These are also used in burglar alarms, fire alarms, detectors used for detection of traffic law defaulters etc.

➢ De Broglie hypothesis

- De Broglie proposed that if the radiations could possess dual nature, matters could also possess dual nature.

- A particle of mass (m), moving with velocity (v) could behave like a wave under suitable conditions. And the corresponding wave related to that matter is called **matter wave.**

➢ De Broglie wavelength

De – Broglie wavelength λ is given as:

$$\boxed{\lambda = \frac{\mathbf{h}}{\mathbf{P}} = \frac{\mathbf{h}}{\mathbf{m}v} = \frac{h\sqrt{1-\frac{v^2}{c^2}}}{m_0 v} = \frac{\mathbf{h}}{\sqrt{\mathbf{2mev}}} = \frac{\mathbf{12.27}}{\sqrt{\mathbf{V}}}}$$

➢ Properties of De - Broglie wavelength

1. Lighter the particle greater is its De – Broglie wavelength.
2. As faster the particle moves, the smaller is its De – Broglie wavelength.
3. The De- Broglie wavelength of a particle is independent of the charge or nature of particle.
4. The matter waves are not electromagnetic in nature. The electromagnetic waves are produced only by accelerated charged particle.

➢ Applications of De - Broglie wavelength

❶ **Electron Microscope:**

Electron microscopes are scientific instruments that use a beam of highly energetic electrons to examine objects on a very fine scale.

❷ **Optical Microscope:**

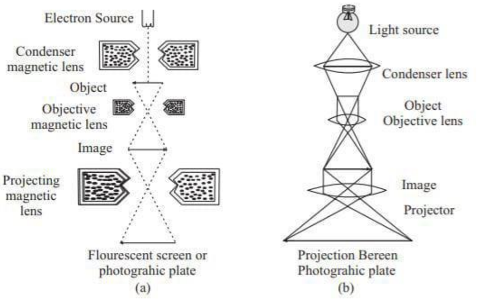

Electron Source
Condenser magnetic lens
Object
Objective magnetic lens
Image
Projecting magnetic lens
Flourescent screen or photograhic plate
(a)
Light source
Condenser lens
Object
Objective lens
Image
Projector
Projection Bereen Photograhic plate
(b)

Fig. 25.8: a) Electron microscope, and **b)** Optical microscope

Question - answer

① MCQs

1. The emission of electrons does not occur in which of the following?
   - (a) Photoelectric Emission
   - (b) Thermionic Emission
   - (c) Secondary Emission
   - (d) X-Ray Emission

Answer: **(d) X-Ray Emission**

2. Identify the process in which an electron escapes from the metal surface.
   - (a) Electron emission
   - (b) Electron displacement
   - (c) Electron transgression
   - (d) Electron movement

Answer: **(a) Electron emission**

3. Which of the following are quick electron emissions?
   - (a) Photoelectric emission
   - (b) Field emission
   - (c) Secondary emission
   - (d) Thermionic emission

Answer: **(b) Field emission**

4. What happens to the kinetic energy of the emitted electrons when the light is incident on a metal surface?
   - (a) It varies with the frequency of light
   - (b) It varies with the light intensity
   - (c) It varies with the speed of light
   - (d) It varies irregularly

Answer: **(a) It varies with the frequency of light.**

5. A photoelectric cell is a device which:
   - (a) Converts light energy into electricity
   - (b) Converts electricity into light energy
   - (c) Stores Light energy
   - (d) Stores Electricity

Answer: **(a) Converts light energy into electricity.**

6. Photons are deflected by:

(a) Magnetic field only (b) Electric field only
(c) Electromagnetic field (d) None of the above

Answer: **(d) None of the above**

7. The photoelectric effect is based on the law of conservation of:

(a) Energy (b) Momentum (c) Mass (d) Angular momentum

Answer: **(a) Energy**

8. Photon does not possess:

(a) Energy (b) Momentum (c) Rest Mass (d) Frequency

Answer: **(c) Rest Mass**

9. Moving mass of photon is**:** **[PYQ NIOS April 2022]**

(a) $\frac{h\upsilon}{\lambda}$ (b) $\frac{h\lambda}{c}$ (c) $\frac{h\upsilon}{c^2}$ (d) $\frac{h}{\lambda c}$

Answer: **(c) $\frac{h\upsilon}{c^2}$**

10. Which among the following shows the particle nature of light?

(a) Photoelectric effect (b) Interference
(c) Refraction (d) Polarization

Answer: **(a) Photoelectric effect**

11. If the intensity of incident radiation in a photo-cell is increased, how does the stopping potential vary?

(a) Increases (b) Remains the same (c) Decreases (d) Infinite

Answer: **(b) Remains the same**

12. If the frequency of the incident radiation is equal to the threshold frequency, what will be the value of the stopping potential?

(a) 0 (b) Infinite (c) 180 V (d) 1220 V

Answer: **(a) 0**

13. How does retarding potential vary with the frequency of light causing photoelectric effect?

(a) Infinite (b) Zero (c) Decreases (d) Increases

Answer: **(d) Increases**

14. The maximum kinetic energy of a photoelectron is 3 eV. What is the stopping potential?

(a) 0 V (b) 3 V (c) 9 V (d) 12 V

Answer: **(b) 3 V**

15. Identify the conclusion of the photoelectric experiment from the following.

(a) Photons are smaller than the electrons
(b) The energy in light comes as small packets
(c) The energy in light comes as huge packets of energy
(d) The energy released by the photoelectric effect is very less

Answer: **(b) The energy in light comes as small packets**

16. How does retarding potential vary with the frequency of light causing photoelectric effect?

(a) Infinite (b) Zero (c) Decreases (d) Increases

Answer: **(d) Increases**

17. Identify the de – Broglie expression from the following.

(a) $\lambda = h \times p$ (b) $\lambda = \frac{h}{p}$ (c) $\lambda = h + p$ (d) $\lambda = h - p$

Answer: **(b)** $\boldsymbol{\lambda = \frac{h}{p}}$

18. What is the ratio of specific charge of particle to the proton?

(a) 1:2 (b) 2:1 (c) 4:1 (d) 1:4

Answer: **(a) 1:2**

19. The velocity of the most energetic electrons emitted from a metallic surface is doubled when the frequency (*v*) of incident radiation is doubled. What is the work function of this metal?

(a) Zero (b) hv/3 (c) hv/2 (d) 2hv/3

Answer: **(d) 2hv/3**

20. Which characteristics of a target does the Mosley's law relate the frequency of X – rays?

(a) Density (b) Atomic number

(c) Atomic weight (d) Interatomic space

Answer: **(b) Atomic number**

②Complete the sentence using an appropriate word:

21. Louis de Broglie, photon, work function, photoelectric effect, particle,

1. The dual nature of light suggests that it can act both as a ---------- and as a wave.

2. When light of certain frequencies shines on a metal surface, it causes the emission of electrons, a phenomenon known as the ---------- effect.

3. ---------- described the effect of quantum mechanics on particles such as electrons showing wave properties.

4. The discrete packets of energy that light can be divided into are called -----.

5. In the photoelectric effect, the minimum energy required to eject an electron from the metal surface is called the ---------- energy.

Answer: **1. particle, 2. photoelectric, 3. Louis de Broglie, 4. photons, 5. Work function**

③Fill in the blanks:

22.

1. The de Broglie wavelength is given by __________ .
2. Lighter the particle greater is its De – Broglie wavelength __________.
3. If __________increases then current in photoelectric tube also increases.
4. The maximum kinetic energy of photoelectrons depends only on ________ not on __________.

Answer: **1. $\frac{h}{p}$, 2. De – Broglie wavelength, 3. Intensity, 4. Frequency, intensity**

23.

1. Rest mass of photon is _________.
2. In _________Electrons emitted by the heating of metals.
3. Work function is measured in _________.
4. The photoelectric effect is based on the law of conservation of________.

Answer: **(1) Zero, (2) thermoinoic emission, (3) electron volt (ev), (4) energy**

④ Match the following:

24. **Match the statement of COLUMN A with most suitable statement of COLUMN B.**

COLUMN A	COLUMN B
1. Thermionic emission	(a) When light of suitable frequency incident on metal surface.
2. Field emission	(b) Electrons emitted by the heating of metals.
3. Photoelectric emission	(c) Electrons emitted by the strong electric field.

Answer: **(1) – (b), 2 – (c), 3 – (a)**

25. **Match the statement of COLUMN A with most suitable statement of COLUMN B.**

COLUMN A	COLUMN B
1. Work function	(i) minimum frequency of incident light required to eject electrons from a metal surface
2. Threshold frequency	(ii) proposed by Louis de Broglie and states that particles can exhibit wave-like properties.
3. Wave particle duality	(iii) Energy required to remove an electron from the surface of a metal.
4. De Broglie hypothesis	(iv) matter as exhibiting both particle and wave characteristics.

Answer: **(1) – (iii), 2 – (i), 3 – (iv), 4 – (ii)**

⑤ True or false

26. The stopping potential in photoelectric emission does not depend upon the frequency of the incident radiation.

⇒ **False**

27. Thermionic emission is dependent on temperature.

⇒ **True**

28. The photoelectric effect is commonly found in solar panels.

⇒ **True**

29. When a proton is accelerated through 1 V, then its kinetic energy will be 1 V.

⇒**False**

30. When the wavelength of an electron increases, the velocity of the electron will also increase.

⇒ **False**

31. While comparing the alpha particle, neutron, and beta particle, the alpha particle has the lowest de – Broglie wavelength.

⇒ **True**

32. In the process of photoelectric emission all the emitted photoelectric posses the same kinetic energy.

⇒ **False**

33. If frequency of radiation incident on a photosensitive surface is doubled, the maximum kinetic energy of emitted photoelectrons also gets doubled.

⇒ **False**

34. De – Broglie wavelength of a moving particle of kinetic energy K is given by the expression $\lambda = \frac{h}{\sqrt{2mk}}$.

⇒ **True**

35. Photons are electrically neutral.

⇒ **True**

36. Number of photon electrons emitted depends upon frequency.

⇒ **False**

⑥ Very short type question answer (2 marks of each)

37. Do non metals show photoelectric effect explain it.

Answer: Yes, the photoelectric effect can occur in non-metals as well. The photoelectric effect is the phenomenon where electrons are emitted from a material when it absorbs electromagnetic radiation, such as light. This effect was first observed in metals, but it has since been observed in non-metals as well. When photons of sufficient energy strike a non-metal, they can cause the emission of electrons, leading to the photoelectric effect.

38. What are main four observations from the experimental study of photo-electric effect? [PYQ NIOS Oct 2021]

Answer:

1. The kinetic energy of photoelectrons increases with light frequency.
2. Electric current remains constant as light frequency increases.
3. Electric current increases with light amplitude.
4. The kinetic energy of photoelectrons remains constant as light amplitude increases.

39. Photos of energy 5eV are incident on a metallic block of work function 2.3 ev. Calculate the maximum kinetic energy of the photoelectrons emitted from the metal surface. [PYQ NIOS april 2022]

Answer: Kinetic Energy lost due to stopping potential = e × 3.5 V = 3.5 eV

So,

From the question, the photoelectric equation becomes, 5 – W = 3.5

$\Rightarrow W = 1.5$ eV

40. The work function of an element is 3.1 eV. Calculate the wavelength of light radiation required to initiate photo emission in this element. ($h = 6.63 \times 10^{-34}$ JS) [PYQ NIOS april 2022]

41. Describe a simple photo electric cell.

Answer: A photoelectric cell, also known as a photocell, is a device that converts light energy into electrical energy based on the photoelectric effect. The fundamental principle behind a photocell is that when light strikes a photosensitive material, it causes electrons to be emitted from the material's surface. These freed electrons can be captured to form an electric current, thus converting light energy into electrical energy.

42. In the photoelectric effect's context, define "stopping potential".

Answer: For a specific frequency of incident radiation, the cut-off or stopping potential is the value of the retarding potential at which the photoelectric current zeroes out.

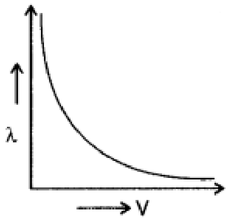
43. Show graphically, the variation of the de- Broglie wavelength (λ) with the potential (V) through which an electron is accelerated from rest.

Answer:

$$\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{\frac{2eV}{m}}}$$

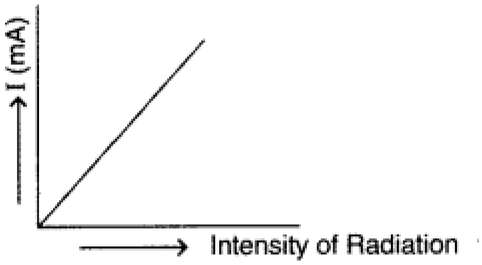
$$= \frac{h}{\sqrt{2meV}}$$

$$= \frac{12.27}{\sqrt{V}}\,\text{Å}$$



44. Show on a plot the nature of variation of photoelectric current with the intensity of radiation incident on a photosensitive surface.

Answer:



45. State one reason to explain why wave theory of light does not support photoelectric effect.

Answer: One reason why wave theory of light does not support photoelectric effect is that the kinetic energy of photo electrons does not depend on the intensity of incident light.

46.

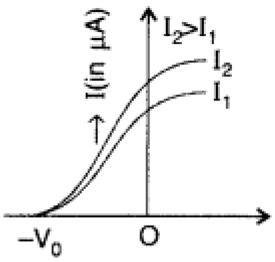
(i) Define the term 'threshold frequency' as used in photoelectric effect.

(ii) Plot a graph showing the variation of photoelectric current as a function of anode potential for two light beams having the same frequency but different intensities I_1 and I_2 ($I_1 > I_2$).

Answer:

(i) Threshold frequency. The minimum frequency v_0 which the incident light must possess so as to eject photoelectrons from a metal surface, is called threshold frequency of the metal.

(ii)



47. Assume that the radiation hitting a metal plate has a frequency higher than its threshold frequency. What would happen if the incidence of radiation was doubled?

(1) Electron kinetic energy & (2) Photoelectric current

Answer: (1) When the frequency of incident radiation doubles, the kinetic energy also doubles.

(2) The number of photoelectrons, or photoelectronic current, won't change if the frequency of the incident radiation is doubled.

48. List two characteristics of photons. Why aren't all photoelectrons produced by a monochromatic photon incident on a photosensitive surface at the same energy? Explicitly justify your response.

Answer: Two features of photons are:

1. The photon has no electrical charge.
2. The energy of a photon is hv.

All photoelectrons do not exit from a monochromatic radiation incident on a photosensitive surface with the same energy as, in addition to the work required to remove electrons from the surface, various (emitted) photoelectrons require varying amounts of work in order to reach the surface.

⑦Short type question answer (3 marks of each)

49. State de Broglie Hypothesis. Derive an expression for the de Broglie wavelength of an elementary particle of mass 'm' and charge 'q' and moving with a velocity 'v' after being accelerated through a potential difference 'V'. **[PYQ NIOS Oct 2021]**

Answer: The de Broglie wavelength is the wavelength, ***λ***, associated with a massive particle and is related to its momentum, ***p***, through the Planck constant, h

$$\lambda = \frac{h}{p}$$

For an electron accelerated by potential V,

$$qV = \frac{p^2}{2m}$$

$$\Rightarrow p = \sqrt{2mqV}$$

$$\text{Hence } \lambda = \frac{h}{\sqrt{2qmV}}$$

50. Discuss free electrons in metals, work function, & types of emission for the ejection of electrons.

Answer: **∗ Free electrons**

In metals, the electrons in the outer shell called the valance electrons of the atoms are loosely bound. They are free to move easily within the metal but are not allowed to leave the surface of the metal. Such freely moving electrons are called free electrons.

∗ Work function

The work function is the minimum or the lowest amount of energy required by an electron to escape from the metallic surface by overcoming the attractive force with the surface of the metal.

The work function is symbolized as o and measured in eV, where eV stands for electron volt. So, eV is the energy required by an electron to escape from the metallic surface. According to the theory of electron emission, there are four types of electron emissions.

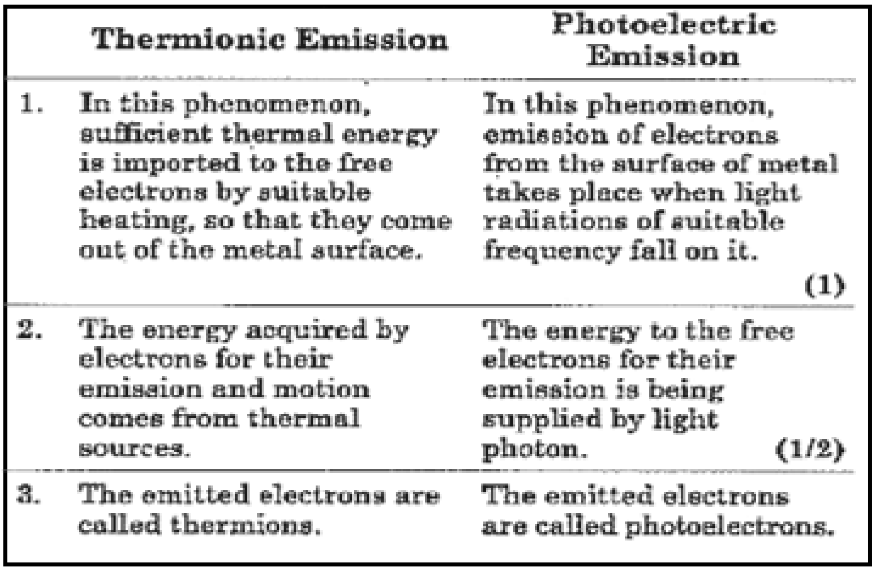
∗ Types of Emission of Electrons

The electron emission from the metallic surface is possible only when the energy supplied is greater than the work function of the metal. The energy required for the various types of electron emission can be supplied to the free electrons by the following physical processes:

1. Thermionic emission
2. Field emission
3. Photoelectric emission

51. **Distinguish between photoelectric emission and thermionic emission.**

Answer:



	Thermionic Emission	Photoelectric Emission
1.	In this phenomenon, sufficient thermal energy is imported to the free electrons by suitable heating, so that they come out of the metal surface.	In this phenomenon, emission of electrons from the surface of metal takes place when light radiations of suitable frequency fall on it. (1)
2.	The energy acquired by electrons for their emission and motion comes from thermal sources.	The energy to the free electrons for their emission is being supplied by light photon. (1/2)
3.	The emitted electrons are called thermions.	The emitted electrons are called photoelectrons.

52. **List three features of the photoelectric effect that can only be explained by Einstein's equation and cannot be explained using the wave theory of light.**

Answer: Here are three features of the photoelectric effect.

- The experimental data does not show that the maximum kinetic energy of the released electron is directly proportional to the strength of incident radiations, but it should. According to wave theory, the maximal kinetic energy of the released electrons should not rely on the incident frequency, but this is not the case.
- The threshold frequency should not exist, according to wave theory. If the light's intensity is high enough for electrons to escape, the light of all frequencies should do so.
- The photoelectric effect shouldn't happen instantly, according to wave theory. The wave's energy cannot be transferred to a specific electron; rather, it is spread to all of the electrons in the lighted region as a whole. Therefore, a delay between the incidence of radiation and the emission of electrons is necessary.

53. Derive Einstein photo electric equation.

Answer: Based on the quantum theory by Planck, Einstein created an equation that can describe the impacts of photoelectric effects which famously got the title of Einstein's Photoelectric Equation later.

The rate of the electron emission from the surface is directly proportional to the frequency of the light and it is defined as the below equation:

$$E = hf$$

E = energy in the emitted electron from the surface, h = Planck's constant and f = frequency of light.

Einstein explains that when a photon is reflected on the metal surface a part of the photon's energy is used to remove electrons from the atom of the metal and another part results in the emission of an electron and kinetic energy from the surface.

Also, $\mathbf{E_k = hf - \emptyset}$

54. Explain laws of photo electric emission?

Answer:

The four laws of photoelectric emission:

1. The velocity of electrons emitted is independent of the intensity of light and depends only upon the frequency (or wavelength) of the incident light.
2. Photoelectric current (or the number of photoelectrons ejected per second) is proportional to the intensity of incident light.
3. For a given metal, there exists a certain minimum frequency below which the emission of electrons stops completely. This frequency is called the threshold frequency.
4. Photoelectric emission is an instantaneous process. So, there is no time logging between the incident of light and the emission of electrons.

⑧Long type question answers (5 marks of each)

55. An alpha particle and a proton are accelerated through the same potential difference. Find the ratio of their de Broglie wavelengths.

[PYQ NIOS Oct 2021]

Answer: The de - Broglie wavelength of a particle of mass m and moving with velocity v is given by

$$\lambda = \frac{h}{mv} \qquad (\because p = mv)$$

De – Broglie wavelength of a proton of mass **m_1** and kinetic energy **k** is given by

$$\lambda_1 = \frac{h}{\sqrt{2m_1k}} (\because p = \sqrt{2mk})$$

$$\lambda_1 = \frac{h}{\sqrt{2m_1qV}} \ldots (i)\ [\because k = qV]$$

For an alpha particle mass m_2 carrying charge q_0 is accelerated through potential V, then

$$\lambda_2 = \frac{h}{\sqrt{2m_2q_0V}}$$

∵ For α – particle $({}_2^4He)$: q_0= 2q and m_2= 4m_1

$$\therefore \lambda_2 = \frac{h}{\sqrt{2 \times 4m_1 \times 2q \times V}} \ldots$$

$$= \frac{4}{\sqrt{2}} \times \frac{\sqrt{2}}{\sqrt{2}}$$

The ratio of corresponding wavelength, from Eqs. (i) and (ii), we get

$$\frac{\lambda_1}{\lambda_2} = \frac{h}{\sqrt{2m_1qV}} \times \frac{\sqrt{2 \times m_1 \times 4 \times 2qV}}{h}$$

We get $\frac{\lambda_1}{\lambda_2} = 2\sqrt{2}$

56. Discuss Einstein's explanation of the photoelectric effect.

Answer: Einstein resolved this problem using Planck's revolutionary idea that light was a particle. The energy carried by each particle of light (called quanta or photon) is dependent on the light's frequency (ν) as shown:

$$E = h\nu$$

Where h = Planck's constant = 6.6261×10^{-34} Js.

Since light is bundled up into photons, Einstein theorized that when a photon falls on the surface of a metal, the entire photon's energy is transferred to the electron.

A part of this energy is used to remove the electron from the metal atom's grasp and the rest is given to the ejected electron as kinetic energy. Electrons emitted from underneath the metal surface lose some kinetic energy during the collision. But the surface electrons carry all the kinetic energy imparted by the photon and have the maximum kinetic energy.

We can write this mathematically as:

Energy of photon = energy required to eject an electron (work function) + Maximum kinetic energy of the electron

$$E = W + KE$$

$$h\nu = W + KE$$

$$KE = h\nu - w$$

At the threshold frequency, ν_0 electrons are just ejected and do not have any kinetic energy. Below this frequency, there is no electron emission. Thus, the energy of a photon with this frequency must be the work function of the metal.

$$w = h\nu_0$$

Thus, Maximum kinetic energy equation becomes:

$$KE = \frac{1}{2}mv^2_{max} = h\nu - h\nu_0 = \frac{1}{2}mv^2_{max} = h(\nu - \nu_0)$$

V_{max} is the maximum kinetic energy of the electron. It is calculated experimentally using the stopping potential. Please read our article on Lenard's observations to understand this part.

$$\text{Stopping potential} = e\nu_0 = 1/2mv^2_{max}$$

Thus, Einstein explained the Photoelectric effect by using the particle nature of light.

57. Describe the Experimental Setup of Davisson Germer Experiment. Observations of Davisson Germer experiment.

Answer:

⁎ The experimental arrangement of the Davisson Germer experiment is discussed below:

- An electron gun comprising a tungsten filament F was coated with barium oxide and heated through a low voltage power supply.
- While applying suitable potential difference from a high voltage power supply, the electron gun emits electrons which were again accelerated to a particular velocity.
- In a cylinder perforated with fine holes along its axis, these emitted electrons were made to pass through it, thus producing a fine collimated beam.
- The beam produced from the cylinder is again made to fall on the surface of a nickel crystal. Due to this, the electrons scatter in various directions.
- The beam of electrons produced has a certain amount of intensity which is measured by the electron detector and after it is connected to a sensitive galvanometer (to record the current), it is then moved on a circular scale.
- By moving the detector on the circular scale at different positions that is changing the θ (angle between the incident and the scattered electron beams), the intensity of the scattered electron beam is measured for different values of angle of scattering.

⁎ Observations of Davisson Germer experiment:

From this experiment, we can derive the below observations:

- We obtained the variation of the intensity (I) of the scattered electrons by changing the angle of scattering, θ.
- By changing the accelerating potential difference, the accelerated voltage was varied from 44V to 68 V.

- With the intensity (I) of the scattered electron for an accelerating voltage of 54V at a scattering angle θ = 50°, we could see a strong peak in the intensity.
- This peak was the result of constructive interference of the electrons scattered from different layers of the regularly spaced atoms of the crystals.
- With the help of electron diffraction, the wavelength of matter waves was calculated to be 0.165 nm.

27

Nuclear fusion and fission

Short summary

What do we learn

Quick Revision

➢ *Introduction*

We all read about energy security and the role of nuclear energy to produce electricity in our nuclear reactors.

We also read about the nuclear bomb.

These are directly or indirectly related to nuclear reaction such as **Nuclear fission** and **Nuclear fusion**.

So in this chapter we will study about the chemical and nuclear reactions, concepts of nuclear fission and nuclear fusion, nuclear reactor and nuclear energy.

➢ *Chemical reaction*

In simple terms a chemical reaction is ***"a process that leads to the chemical transformation of one set of chemical substances to another."***

Example: Interaction of carbon atoms with oxygen molecules to produce carbon dioxide: $\mathbf{C + O_2 \rightarrow CO_2 + 4.08\ ev}$

In this chemical reaction, 4.08 ev energy is released for each reacting carbon atom. It is called the **Binding Energy**.

∗ The important points to be noted in chemical reactions are –:

- Energies of the order of 10 eV are involved.
- Change of mass is of the order of 10^{-35} kg, which is extremely small the mass is conserved.
- The total number of atoms of each type on the right hand side of the chemical equation is always equal to the total number of atoms of each type on the left hand side.

➢ *Endothermic reaction*

Reactions which require energy to be supplied to be initiated are **Endothermic**.

➢ *Endothermic reaction*

Reactions which result in release of energy are said to be **Exothermic**.

Exothermic Chemical reaction:
$C + O_2 \rightarrow CO_2 + 4.08$ ev

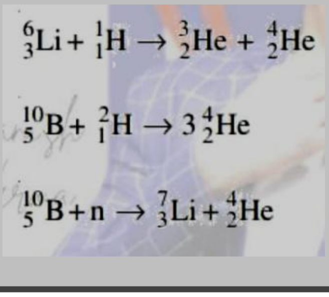
Endothermic chemical reaction:
$CO_2 + 4.08$ ev $\rightarrow C + O_2$

➢ *Nuclear reaction*

"A process in which the nucleus of an atom is changed by being split apart or joined with the nucleus of another atom is called nuclear reaction."

Nuclear reactions can also be produced by protons, deuterons, neutrons and other light nuclei.

Some typical examples of nuclear reactions produced by protons, deutrons and neutrons are:



$$^{6}_{3}Li + ^{1}_{1}H \rightarrow ^{3}_{2}He + ^{4}_{2}He$$

$$^{10}_{5}B + ^{2}_{1}H \rightarrow 3\,^{4}_{2}He$$

$$^{10}_{5}B + n \rightarrow ^{7}_{3}Li + ^{4}_{2}He$$

➢ *Conservation laws for nuclear reaction*

1. The sum of the mass numbers of the reactants is equal to the sum of mass numbers of the products.

2. The sum of atomic numbers of the reactants is equal to the sum of atomic numbers of the products.

3. Nuclear reactions follow the law of conservation of energy.

4. Nuclear reactions follow the law of conservation of momentum, which results in distribution of kinetic energy among various product nuclei.

➢ *Types of Nuclear reaction*

There are two types of nuclear reaction:

1. Nuclear fission reaction
2. Nuclear fusion reaction

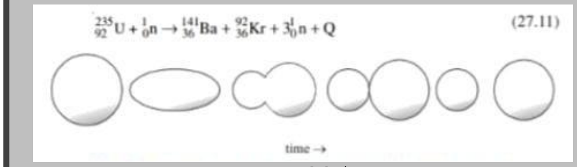
Nuclear Fission: Nuclear fission is the splitting of a heavy nucleus into two lighter nuclei.

Nuclear Fusion: The process by which two lighter nuclei are combined to form a heavy nucleus is known as nuclear fusion.

➢ *Nuclear fission*

"Nuclear fission refers to the splitting of an atomic nucleus into two or lighter nuclei."

- Scientist named Fermi was the one who performed first nuclear fission reaction.
- He considered the sample of $^{235}_{92}U$ and bombarded it with a neutron $^{1}_{0}n$ i.e.



$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{36}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + Q \qquad (27.11)$$

"A substance like $^{235}_{92}U$ which undergoes fission by thermal neutrons is called a fissile material."

NOTE: Other fissile materials are $^{233}_{90}TH$, $^{233}_{92}U$, $^{239}_{93}Pu$

➢ *Nuclear chain reaction*

"A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus."

U^{235} + n → fission + 2 or 3 n + 200 MeV

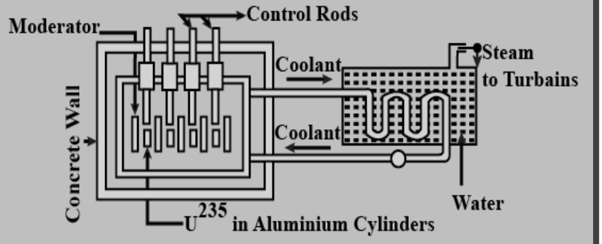
➢ *Nuclear reactor*

"When the rate of production of neutrons equals the rate of loss of neutrons, the reaction is said to be self-sustained."

The device designed to maintain a self - sustained and controlled chain reaction is called a ***'Nuclear reactor'***.

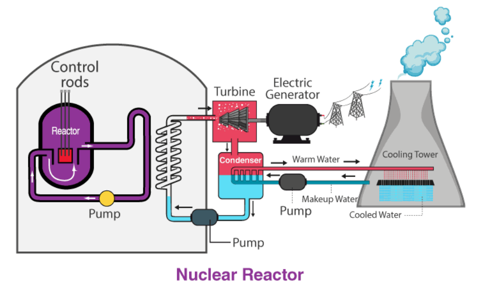
- Nuclear reactors are useful in producing electricity.

- A nuclear reactor is an arrangement to generate electricity which makes use of nuclear fission.


Moderator
Control Rods
Steam
to Turbains
Coolant
Coolant
Concrete Wall
Water
U^{235} in Aluminium Cylinders

➢ *More about Nuclear reactor*

∗ Schematic diagram –:


Control rods
Reactor
Pump
Turbine
Electric Generator
Condenser
Warm Water
Cooling Tower
Makeup Water
Pump
Cooled Water
Pump
Nuclear Reactor

∗ Advantages of nuclear reactor –:

- Energy released is extremely large.
- Needs fuel in extremely small quantity.

∗ Disadvantages of nuclear reactor –:

- Spent fuel is highly radioactive and extremely hazardous to all life forms.
- Accumulation of radioactive waste.

➢ *Nuclear fusion*

"Nuclear fusion is when two or more atomic nuclei fuse to form a single heavier nucleus."

- In a nuclear fusion reaction two lighter nuclei combine to form a relatively heavier nucleus.
- In this process huge amount of energy is also released.
- Temperature at which protons would have enough energy to overcome the coulomb's barrier is very high.

➢ *Thermonuclear fusion*

- Increasing the temperature of the material until the particles have enough energy due to their thermal motions alone –to overcome the coulomb barrier.
- For thermonuclear fusion, extreme conditions of temperature and pressure are required.
- Example of Thermonuclear fusion is generation of energy in stars.

For example:

From the sun we get large amount of energy and this energy generated due to the thermonuclear fusion reaction taking place in the sun.

➢ *Energy in suns and stars*

Every star in the universe, including the sun, is alive due to nuclear fusion.

- It is through this process that they produce an enormous amount of heat and energy.
- The pressure at the core of any star is tremendously high, and that is where the nuclear fusion reaction occurs.

The tremendous amount of energy released in a thermo – nuclear reaction is the source of energy in stars.

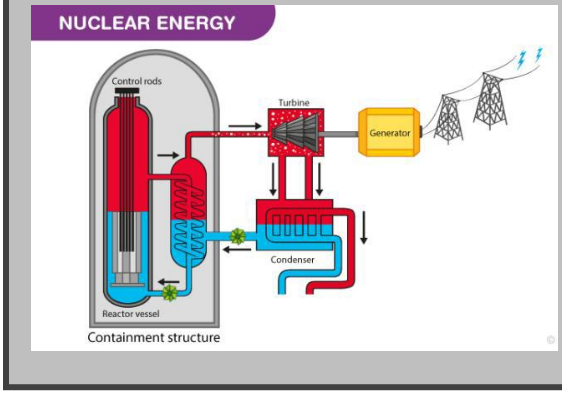
NOTE: The quantity of hydrogen in the sun is sufficient to keep it shining for nearly 8 billion years more.

➢ *Nuclear energy*

"Nuclear energy is the energy that holds together the nuclei of atoms."

Nuclear energy is obtained from nucleus by either:

- Breaking of heavy nucleus into relatively lighter nuclei known as nuclear fission.
- Combining 2 lighter nuclei to form a heavy nucleus known as nuclear fusion.
- Electrical energy can be harnessed from nuclear energy.



➢ *Advantages of nuclear energy*

• Low – cost energy • Reliable • Zero – carbon emission • High energy density • Promising future energy supply

➢ *Disadvantages of nuclear energy*

• Environmental impact • water intensive • risk of nuclear accidents • radioactive waste • non – renewable

➢ *Applications of nuclear energy*

• Nuclear technology • Nuclear medicine • Nuclear Technology is used in Industries

Question – Answer

① MCQs

1. **Which of the following is a type of nuclear reaction?**

(A) Combustion (B) Fusion (C) Oxidation (D) Reduction

Answer: **(B) Fusion**

2. **In a nuclear fission reaction, a heavy nucleus splits into:**

(A) Two lighter nuclei (B) One lighter nucleus
(C) Electrons (D) Neutrons only

Answer: **(A) Two lighter nuclei**

3. **Which of the following particles is commonly emitted during a nuclear decay process?**

(A) Proton (B) Neutron (C) Alpha particle (D) Electron

Answer: **(C) Alpha particle**

4. **In nuclear reactor, heavy water is used to:** **[PYQ NIOS April 2022]**

(A) Enhance the speed of fast moving neutrons
(B) Reduce the speed of fast moving neutrons
(C) Absorb heat energy
(D) Absorb extra neutrons

Answer: **(B) Reduce the speed of fast moving neutrons**

5. **The energy released in a nuclear reaction is due to:**

(A) Chemical bonds (B) Nuclear binding energy
(C) Electromagnetic radiation (D) Thermal energy

Answer: **(B) Nuclear binding energy**

6. **Which isotope of uranium is commonly used as fuel in nuclear reactors?**

(A) Uranium-235 (B) Uranium-238
(C) Uranium-232 (D) Uranium-233

Answer: **(A) Uranium-235**

7. In a nuclear fusion reaction, which of the following occurs?

(A) A heavy nucleus splits into two lighter nuclei
(B) Two light nuclei combine to form a heavier nucleus
(C) An electron is absorbed by a nucleus
(D) A neutron is emitted by a nucleus

Answer: **(B) Two light nuclei combine to form a heavier nucleus**

8. The process in which a nucleus captures a neutron and undergoes fission is called:

(A) Nuclear fusion (B) Alpha decay
(C) Beta decay (D) Neutron capture

Answer: **(D) Neutron capture**

9. Which of the following is an example of a controlled nuclear reaction?

(A) Nuclear bomb explosion (B) Chemical explosive
(C) Nuclear reactor operation (D) Natural radioactive decay

Answer: **(C) Nuclear reactor operation**

10. The number of neutrons in the nucleus of $^{27}_{13}\mathrm{Al}$ **[PYQ NIOS Jan 2021]**

(A) 13 (B) 27 (C) 40 (D) 14

Answer: **(D) 14**

11. What is the role of a moderator in a nuclear reactor?

(A) Absorb neutrons (B) Slow down neutrons
(C) Speed up neutrons (D) Shield radiation

Answer: **(B) Slow down neutrons**

12. The particle '*x*' emitted in the nuclear reaction: $^{4}_{2}\mathrm{He} + ^{14}_{7}\mathrm{N} \rightarrow ^{17}_{8}\mathrm{O} + x$, is: **[PYQ NIOS Jan 2021]**

(A) electron (B) photon (C) proton (D) neutron

13. A radioactive nucleus emits a beta particle, then the parent and daughter nuclei are:

(A) Isotones (B) Isotopes (C) Isomers (D) Isobars

Answer: (D) Isobars

14. Sun's radiant energy is due to:

(A) Nuclear Fusion (B) Nuclear Fission

(C) Photoelectric Effect (D) Radioactive Decay

Answer: (A) Nuclear Fusion

15.The neutron was discovered by whom?

(A) Marie Curie (B) Pierre Curie

(C) Rutherford (D) James Chadwick

Answer: (D) James Chadwick

16. Which of the following is a correct statement?

(A) Beta rays are the same as for cathode rays

(B) Gamma rays are high energy neutrons

(C) Alpha particles are singly ionized helium atoms

(D) Protons and neutrons have the same mass

Answer: (A) Beta rays are the same as for cathode rays

17. Which is a non-central force?

(A) Electrostatic force (B) Nuclear force

(C) Gravitational force (D) Spring force

Answer: (B) Nuclear force

18. The energy released in the fission of one atom of uranium-235 is approximately:

(A) 200 MeV (B) 2 MeV (C) 200 keV (D) 2 keV

Answer: (A) 200 MeV

19.**In nuclear reactions, there is a conservation of:** **[PYQ NIOS Oct 2021]**

(A) Mass only (B) Energy only

(C) Momentum only (D) Mass, Energy and Momentum

Answer: **(C) Momentum only**

20.**Which one of the following is not a nuclear power centre?**

(A) Kakrapara (B) Narora (C) Champera (D) Kota

Answer: **(C) Champera**

②Complete the sentence using an appropriate word:

21. **neutrons, gamma, energy, fusion, fission**

1. During a nuclear fission reaction, a heavy nucleus splits into smaller nuclei, along with the release of _________ .
2. The process in which a uranium-235 nucleus absorbs a neutron and splits into smaller fragments is known as nuclear _________ .
3. The primary source of energy in stars, including our sun, is the process of nuclear _________ .
4. One of the products of nuclear fission of uranium-235 is _________ , which is a critical factor in sustaining a chain reaction.
5. During the nuclear fission of uranium-235, the immediate products include smaller nuclei, free neutrons, and _________ radiation.

Answer: (1) energy, (2) fission, (3) fusion, (4) neutrons, (5) gamma

③Fill in the blanks:

22.

1. Beta rays are the same as for _________ rays.
2. _________are discovered by James Chadwick.
3. Nuclear reactor operation is a _________reaction.
4. Example of Thermonuclear fusion is generation of _________in stars.

Answer: (1) cathode, (2) neutron, (3) nuclear, (4) energy

23.

1. Nuclear reactors are useful in producing _________.
2. According to the conservation law for nuclear reaction, the sum of the mass numbers of the _________is equal to the sum of mass numbers of the --------- products.
3. Reactions which result in release of energy are said to be _________.
4. Reactions which require energy to be supplied to be initiated are _________.

Answer: (1) Electricity, (2) reactants , products (3) exothermic, (4) endothermic

④ Match the following:

24. **Match the statement of COLUMN A with most suitable statement of COLUMN B.**

COLUMN A	COLUMN B
(i) A type of nuclear reaction where two light nuclei combine to form a heavier nucleus.	(a) Nuclear fission
(ii) A type of nuclear reaction where a nucleus splits into smaller nuclei.	(b) Nuclear fusion

Answer: **(i) – (b) , (ii) – (a)**

25. **Match the statement of COLUMN A with most suitable statement of COLUMN B.**

COLUMN A	COLUMN B
(A) A device used to initiate and control a sustained nuclear chain reaction.	a. Control roads
(B) Devices used in nuclear reactors to control the fission rate by absorbing neutrons.	b. Critical mass
(C) A substance used in reactors to slow down neutrons.	c. Moderator
(D) A mass of fissile material needed to sustain a chain reaction.	d. Nuclear reactor

Answer: **(A) – d, (B) – a, (C) – c, (D) - b**

⑤ True or false

26.Nuclear chain reactions can be controlled in a nuclear reactor.

⇒ **True**

27.In nuclear fusion, a heavy nucleus splits into two lighter nuclei.

⇒ **False**

28.Nuclear fission releases more energy than nuclear fusion per reaction.

⇒ **False**

29.Uranium-235 is commonly used as fuel in nuclear fission reactors.

⇒ **True**

30.Control rods in a nuclear reactor are used to speed up the chain reaction.

⇒ **False**

31.Hydrogen isotopes deuterium and tritium are used in nuclear fusion reactions.

⇒ **True**

32.A nuclear chain reaction occurs when each fission event causes only one subsequent fission.

⇒ **False**

33.Moderators in nuclear reactors slow down neutrons to sustain the chain reaction.

⇒ **True**

34.Nuclear fusion requires extremely high temperatures to overcome repulsive forces between nuclei.

⇒ **True**

35.Gamma rays are a common byproduct of both nuclear fission and nuclear fusion.

⇒ **True**

36. Nuclear energy can be used to generate electricity without producing greenhouse gases directly.

⇒ **True**

37. Nuclear fission occurs naturally in the Sun, providing its energy.

⇒ **False**

38. Thermonuclear reactions are another name for nuclear fusion reactions.

⇒ **True**

39. Nuclear reactors can safely dispose of nuclear waste without any long-term storage concerns.

⇒ **False**

40. The process of nuclear fusion powers hydrogen bombs.

⇒ **True**

⑥ Very short type question answer (2 marks of each)

41. What is a nuclear chain reaction and how is it controlled in a nuclear reactor?

Answer: A nuclear chain reaction is a series of nuclear fissions where each fission event causes further fission events. It is controlled in a nuclear reactor using control rods, which absorb excess neutrons to regulate the rate of the reaction.

42. Explain the process of nuclear fusion and where it commonly occurs.

Answer: Nuclear fusion is the process in which two light atomic nuclei combine to form a heavier nucleus, releasing a large amount of energy. This process commonly occurs in the Sun and other stars, where the high temperatures and pressures enable the fusion of hydrogen nuclei into helium.

43. Describe nuclear fission and name an element commonly used in this process.

Answer: Nuclear fission is the splitting of a heavy atomic nucleus into two lighter nuclei, accompanied by the release of energy and neutrons. Uranium-235 is a commonly used element in nuclear fission.

44. What is nuclear fusion? Write an equation of nuclear fusion to support your answer. **[Sample paper]**

Answer: The process in which two nuclei of lighter elements (such as hydrogen) fuse to form a heavier nucleus (such as helium), and a neutron is emitted, is called nuclear fusion. A large amount of energy is released in this process.

45. What are the main challenges in achieving controlled nuclear fusion on Earth?

Answer: The main challenges in achieving controlled nuclear fusion include reaching and maintaining the extremely high temperatures (millions of degrees) and pressures needed for fusion to occur, and containing the hot plasma in which fusion reactions take place.

46.Compare the energy released by nuclear fusion and nuclear fission.

Answer: Nuclear fusion releases significantly more energy per reaction compared to nuclear fission. Fusion reactions, such as those occurring in the Sun, release vast amounts of energy by combining light nuclei, whereas fission releases energy by splitting heavy nuclei.

47.Out of fission and fusion which is more efficient a nuclear reaction to convert mass into energy and why? **[PYQ NIOS Jan 2021]**

Answer: In summary, fusion is more efficient than fission in converting mass into energy because it releases more energy per unit mass of fuel used. This higher efficiency is due to the greater difference in binding energy per nucleon between the reactants and the products in fusion reactions compared to fission reactions.

48.What is Uranium-235, and why is it important in nuclear reactors?

Answer: Uranium-235 is an isotope of uranium that is fissile, meaning it can sustain a nuclear chain reaction. It is important in nuclear reactors because it serves as the primary fuel for the fission process.

49.How does a nuclear reactor generate electricity?

Answer: In a nuclear reactor, the energy released from nuclear fission heats water to produce steam. This steam drives turbines connected to generators, which produce electricity.

50.Discuss the environmental benefits and risks associated with nuclear energy.

Answer: Benefits of nuclear energy include low greenhouse gas emissions during operation, making it a cleaner alternative to fossil fuels. However, risks include the potential for nuclear accidents, the long-term storage of radioactive waste, and the high costs of building and decommissioning nuclear power plants.

⑦Short type question answer (3 marks of each)

51.Complete the following nuclear reactions:

(a) $^{10}_{5}B + ^{1}_{0}n \longrightarrow ^{4}_{2}He + \ldots$

(b) $^{94}_{42}Mo + ^{2}_{1}H \longrightarrow ^{95}_{43}Te + \ldots$

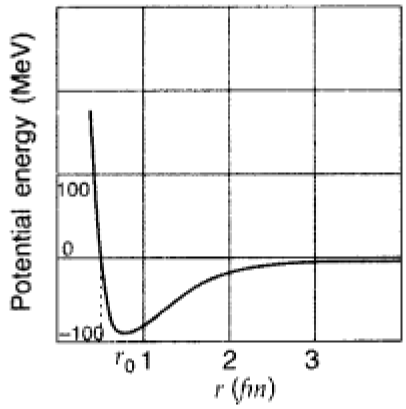
Answer:

(a) $^{10}_{5}B + ^{1}_{0}n \longrightarrow ^{4}_{2}He + ^{7}_{3}Li$

(b) $^{94}_{42}Mo + ^{2}_{1}H \longrightarrow ^{95}_{43}Te + ^{1}_{0}n$

52.Draw a plot of potential energy of a pair of nucleons as a function of their separation. Also conclude the important facts from the graph.

Answer: A plot of the potential energy between two nucleons as a function of distance is shown in the diagram.



Important conclusions from the graph:

(i) The nuclear force is much stronger than the Coulomb force acting between charges or the gravitational forces between masses. The nuclear binding force has to dominate over the Coulomb repulsive force between protons inside the nucleus. This happens only because the nuclear force is much stronger than the coulomb force. The gravitational force is much weaker than even Coulomb force.

(ii) The nuclear force between two nucleons falls rapidly to zero as their distance is more than a few femtometers. This leads to saturation of forces in a medium or a large-sized nucleus, which is the reason for the constancy of the binding energy per nucleon.

(iii) The nuclear force between neutron- neutron, proton-neutron and proton-proton is approximately the same. The nuclear force does not depend on the electric charge.

53. What is meant by nuclear fission and chain reaction? How is a chain reaction controlled in a nuclear reactor? Name any two fissile materials.
[PYQ NIOS Oct 2022]

Answer: When slow neutrons strike the radioactive nuclei, three new neutrons and a tremendous amount of energy is released. These new neutrons can further strike the other radioactive nuclei under the suitable conditions.

A chain reaction in nuclear fission can be controlled using moderators by absorbing neutrons emitted in the fission process and preventing them from striking other radioactive nuclei. Moderators like graphite, heavy water have a unique property of absorbing neutrons.

Uranium -233 and Uranium-235 are the two fissile materials.

54. Answer the following questions, giving reasons:

(i) Why is it that nuclei with a mass number (A) between 30 and 170 are found to have a constant binding energy per nucleon?

(ii) Energy is released during the breakdown of a heavy nucleus with mass number A = 240 into two nuclei, A = 120.

(iii) It is discovered that it is very challenging to experimentally detect neutrinos (or antineutrinos) in -decay.

Answer:

(i) Nuclear weapons have a limited range. A sufficiently massive nucleus will allow some of a specific nucleon's neighbours within the nuclear force's range to affect it. The saturation property of the nuclear force is the characteristic that a specific nucleon only affects nucleons adjacent to it.

(ii) The parent nucleus's binding energy per nucleon is lower than that of the two offspring nuclei. This procedure results in the release of this enhanced binding energy.

(iii) Neutrinos are massless, chargeless particles with little interaction with other particles. As a result, they may only go through a lot of material if they are seen.

55. Describe how radioactive nuclei can emit β-particles despite the absence of these particles in atomic nuclei. Therefore, clarify why a radioactive nuclide's mass number does not change throughout decay.

Answer: A nucleus does not contain beta particles (or electrons) as such. The following equation describes how a neutron can occasionally decay into a proton, an electron, and an antineutrino in the case of a radioactive nuclide:

$${}^{0}_{1}\mathrm{n} \rightarrow {}^{0}_{1}\mathrm{H} + e^{-10} + v + Q$$

Where the antineutrino particle's mass and charge are both zero, the proton from the produced particles stays inside the nucleus, while the electron and antineutrino leave the nucleus. This electron is the one emitting a beta particle.

The mass number of the nuclide doesn't change during -decay because, similar to the emission process, one proton is created in the nucleus at the expense of a neutron since both have the same mass number.

56. Mention four characteristics of nuclear force. **[PYQ NIOS Oct 2022]**

Answer: Nuclear force is the force that binds the neutrons and protons in a nucleus together. The following are the few characteristics of nuclear force –:

1. It is attractive in nature but with a repulsive core. That is the reason that the nucleus is held together without collapsing in itself

2. Nuclear force is identical for all nucleons.

3. At a distance less than 0.7 Fermi, this force becomes repulsive. It is one of the most interesting properties of nuclear force, as this repulsive component of the force is what decides the size of the nucleus.

4. The nuclear forces are dependent on spin or angular momentum of nuclei.

57. Write difference between nuclear fusion and nuclear fission.

Answer: Difference between nuclear fusion and nuclear fission:

Nuclear fission:

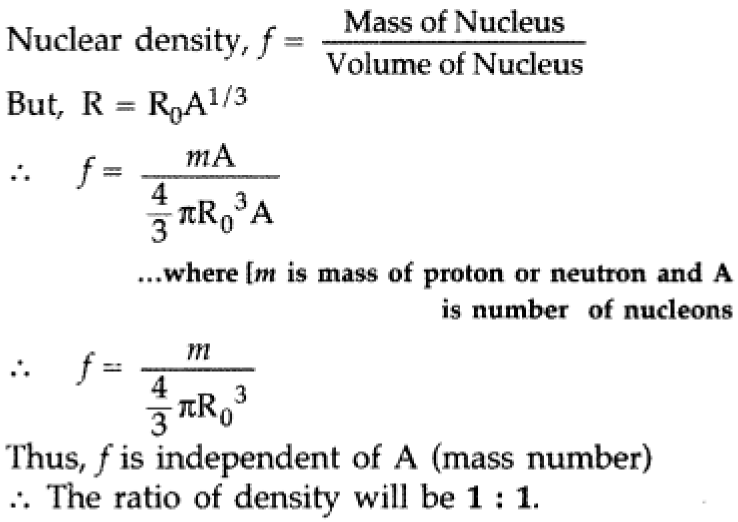
- In this prosses a heavy nucleus splitted into two lighter nuclei.
- This process is possible at normal temperature.
- Per fission released energy is very high (200 MeV)

Nuclear fusion:

- In this process two lighter nuclei fused together to form a heavy nucleus.
- This process is possible at very high temperature.
- Per fusion released energy is comparatively less (24 MeV).

58. Two nuclei have mass numbers in the ratio 1: 2. What is the ratio of their nuclear densities?

Answer:



Nuclear density, $f = \frac{\text{Mass of Nucleus}}{\text{Volume of Nucleus}}$

But, $R = R_0 A^{1/3}$

$$\therefore \quad f = \frac{mA}{\frac{4}{3}\pi R_0^{\,3} A}$$

...where [m is mass of proton or neutron and A is number of nucleons

$$\therefore \quad f = \frac{m}{\frac{4}{3}\pi R_0^{\,3}}$$

Thus, f is independent of A (mass number)

$\therefore$ The ratio of density will be **1 : 1**.

59. Two radioactive samples, X, Y have the same number of atoms at t = 0. Their half lives are 3h and 4h respectively. Compare the rates of disintegration of the two nuclei after 12 hours.

Answer:

Given : $N_X = N_Y$ at $t = 0$

$$(T_X)_{1/2} = 3h, \quad (T_Y)_{1/2} = 4h, \; t = 12h, \quad \frac{R_X}{R_Y} = ?$$

The decay equation is $\frac{dN}{dt} = -\lambda N = N_0\, e^{-\lambda t}$

Given time $= 12\,h = 4(T_X)_{1/2} = 3(T_Y)_{1/2} \qquad \ldots(i)$

$$\therefore \quad \frac{N_X}{N_0} = \left(\frac{1}{4}\right)^4 = \frac{1}{16} \text{ or } N_X = \frac{N_0}{16}$$

$$\text{and} \quad \frac{N_Y}{N_0} = \left(\frac{1}{2}\right)^3 = \frac{1}{8} \text{or } N_Y = \frac{N_0}{8}$$

$$R_X = \left(\frac{dN}{dt}\right)_X = \frac{0.693}{(T_{1/2})_X} \cdot \frac{N_0}{16}$$

$$R_Y = \left(\frac{dN}{dt}\right)_Y = \frac{0.693}{(T_{1/2})_Y} \cdot \frac{N_0}{8}$$

60. Energy generation in stars is due to nuclear fusion.

(a) How a nuclear fusion is occurred?

(b) The energy released in nuclear fission process with uranium is of the order of ________.

Answer:

a) At the center of the star there is huge amount of mass which is surrounding, squeezing down all sides. There is hydrogen gas in the core of the stars. It gets squeeze together so tightly that four hydrogen nuclei combine to form one helium atom. This is called nuclear fusion. In the process some of the mass of the hydrogen atoms is converted into energy in the form of light.

b) The energy released in nuclear fission process with uranium is of the order of 200 MeV.

61. For greater stability, a nucleus should have greater value of binding energy per nucleon. Why?

Answer: Binding energy is the energy that holds a nucleus together and is equal to the mass defect of the nucleus. For stable nucleus, we can see that native prefers even number of protons and an even number of neutrons. The odd combination of protons and neutrons in the nucleus are very less and are only found in lighter elements. For elements with large number of protons in the nucleus, the coulomb electrostatic force of repulsion becomes significant and the number of neutrons must be greater to compensate this repulsion effect.

Therefore the basic point is that the binding energy of a nucleon is directly proportional to the stability of the nucleus, Since stability is what determines whether the nucleus will decay, which is ultimately affected by the binding energy.

⑧Long type question answers (5 marks of each)

62.Explain what are nuclear fission and fusion giving an example of each. Write down the formulae for energy generated in each of these processes.

Answer:

Nuclear Fission

When the nucleus of an atom splits into lighter nuclei through a nuclear reaction the process is termed as nuclear fission. This decay can be natural spontaneous splitting by radioactive decay, or can actually be simulated in a lab by achieving necessary conditions (bombarding with neutrinos). The resulting fragments tend to have a combined mass which is less than the original. The missing mass is what is converted into nuclear energy in the above reaction. Therefore, nuclear fission is defined as:

The process in nuclear physics in which the nucleus of an atom splits into two daughter nuclei.

Nuclear fusion

All matter is made of tiny atoms. All atoms have a nucleus at their core, where most of their mass is concentrated. In specific circumstances, it is possible for this nucleus to undergo certain changes. Nuclear fusion (as the name suggests) is a process of combining small atoms, resulting in heavier atoms with more energy. Nuclear fission is splitting of the nucleus of a heavier atom into a smaller one.

63.What is a nuclear reactor, and describe its main components?

Answer: A nuclear reactor is a device used to initiate and control a sustained nuclear chain reaction. Reactors are primarily used for generating electricity, although they also have applications in research, medicine, and the production of isotopes for various uses.

Main Components of a Nuclear Reactor:

- Fuel Rods (or Fuel Assemblies):

- Function: These contain the fissile material, typically uranium-235 or plutonium-239, which undergoes fission to release energy.
- Details: The fuel is often in the form of ceramic pellets packed into metal tubes, forming rods that are grouped together to form fuel assemblies.

- Moderator:
  - Function: The moderator slows down the fast neutrons produced during fission to thermal (slow) neutrons, which are more likely to cause further fission.
  - Materials: Common moderators include heavy water (D_2O), light water (H_2O), and graphite.

- Control Rods:
  - Function: These rods absorb neutrons and are used to control the rate of the nuclear reaction. By inserting or withdrawing them from the reactor core, the reaction rate can be increased or decreased.
  - Materials: Typically made from neutron-absorbing materials such as cadmium, hafnium, or boron.

- Coolant:
  - Function: The coolant transfers heat away from the reactor core to a steam generator or directly to turbines in some reactor designs.
  - Materials: Common coolants include water (both ordinary and heavy), liquid metals (like sodium or lead), and gases (such as carbon dioxide or helium).

- Pressure Vessel or Reactor Core:
  - Function: This is the container that houses the reactor core (fuel rods, moderator, and coolant). It is designed to withstand high pressures and temperatures.
  - Details: The pressure vessel ensures the structural integrity of the reactor and contains the coolant.

64. Discuss the positive and negative environmental impacts of nuclear energy production.

Answer: Nuclear energy production has several environmental impacts, both positive and negative. Here is a detailed discussion of these impacts:

∗ Positive Environmental Impacts

1. Low Greenhouse Gas Emissions:

Nuclear power plants produce minimal greenhouse gas emissions during operation compared to fossil fuel-based power plants. This makes nuclear energy a viable option for mitigating climate change and reducing global carbon footprints.

2. Reduced Air Pollution:

Nuclear power generation does not produce air pollutants like sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter, which are common byproducts of burning fossil fuels. This results in better air quality and fewer health problems related to air pollution.

3. High Energy Density:

Nuclear fuel has a much higher energy density compared to fossil fuels, meaning a small amount of nuclear fuel can produce a large amount of energy. This reduces the overall environmental footprint of fuel extraction, transportation, and storage.

∗ Negative Environmental Impacts

1. Radioactive Waste:

The most significant environmental challenge of nuclear energy is the production of radioactive waste, which remains hazardous for thousands of years. Proper long-term storage and management are crucial to prevent environmental contamination.

2. Thermal Pollution:

Nuclear reactors typically release large amounts of heat into water bodies, which can cause thermal pollution. This can negatively impact aquatic ecosystems by altering temperature regimes, which can affect species composition and biological processes.

3. **Risk of Accidents:**

Although rare, nuclear accidents (such as those at Chernobyl and Fukushima) can have severe and long-lasting environmental consequences. Radioactive contamination can affect large areas, rendering them uninhabitable and harming wildlife and human populations.

4. **Uranium Mining:**

The extraction and processing of uranium ore can have significant environmental impacts, including habitat destruction, soil and water contamination, and exposure of workers and nearby communities to radioactive materials and other hazardous substances.

5. **Water Use:**

Nuclear power plants require substantial amounts of water for cooling. This can strain local water resources, particularly in arid regions or during periods of drought. Additionally, water withdrawal and discharge can harm aquatic life.

65. Explain the principle and working of a nuclear reactor with the help of a labelled diagram.

Answer:

Nuclear reactor:

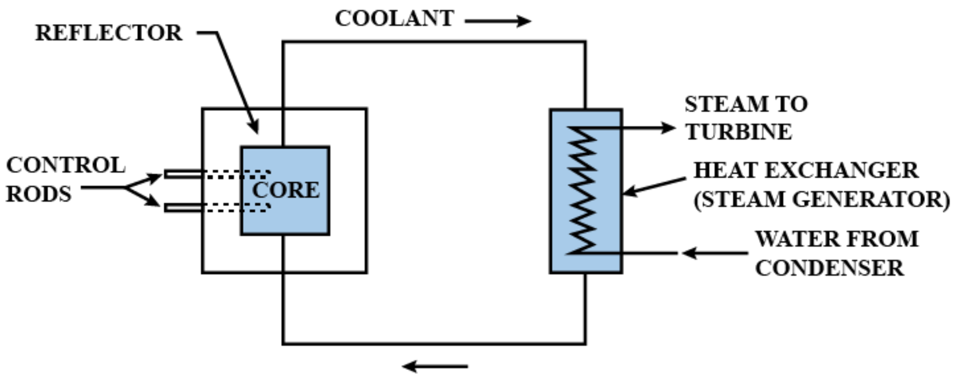
Principle: It works on the principle of achieving controlled chain reaction of Uranium 238_{U} enriched with 235_{U} and as a result generating huge amount of energy. The controlled chain is made possible by:

- Slowing down the fission neutrons to thermal neutrons by using a moderator.
- Inserting rods that can absorb neutrons(control rods) and use them to maintain the reaction rate.

Working:

- In general the fuel used is 235_{U} which is filled in aluminium cylindrical rod.

- The moderator used are D_2O heavy water, salt water and graphite block.
- The materials like Beryllium and Cadmium rods are used as control rods which controls the chain reaction by absorbing the neutron emitted in the nuclear reaction.
- Cold water is circulated through the water pipes surrounding ht nuclear reactor to absorb heat.


REFLECTOR
COOLANT
CONTROL RODS
CORE
STEAM TO TURBINE
HEAT EXCHANGER (STEAM GENERATOR)
WATER FROM CONDENSER

28

Semiconductor and semiconducting device

Short summary

What do we learn

Quick Revision

➢ Introduction

"Electronics is the branch of science which deals with the electron flow through a vacuum, gas or semiconductor."

Scientists have studied the electrical nature of materials and developed a concept of **energy bands** in terms of which solids can be classified as conductors, semiconductors and insulators.

➢ Classification of solids

Classification of solids on the basis of conductivity –:

1) **Conductors:** conductors are those substances through which electricity can pass easily. E.g. all metals are conductors.

2) **Insulators:** insulators are those substances through which electricity cannot pass. E.g. wood, rubber, mica

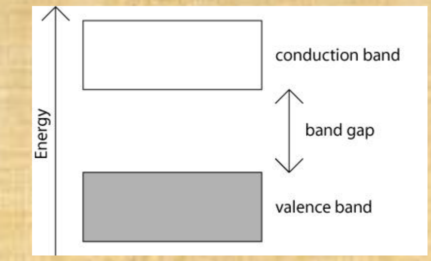
3) **Semiconductors:** semiconductors are those substances whose conductivity lies between conductors and insulators. E.g. germanium, silicon, carbon etc.

➢ Energy bands in solids

∗ Band theory:

Band: The 'band' of a material is used for explaining a variation in its physical properties of conduction.

- Within the limits of energy, electrons orbit the positive nucleus of a single atom.
- Energy levels in many atoms reorganize into two bands, the **valence band and the conductive band**. The lower level of electrons is in the valence band, and the higher level of electrons is in the conduction band.
- There is an energy gap between the bands where electrons cannot exist.
- Electrons move when conduction occurs, and for this to happen, there must be spaces in the energy bands for the electrons to move into.



Energy band

In a crystal due to inter- atomic interaction valence electrons of one atom are shared by more than one atom in the crystal.

Now splitting of energy levels takes place. The collection of these closely spaced energy levels is called an **Energy band**.

Valence band

This energy band contains valence electrons. This band may be partially or completely filled with electrons but never be empty.

The electrons in this band are not capable of gaining energy from external electric field to take part in conduction of current.

Conduction band

This band contains conduction electrons. This band is either empty or partially filled with electrons.

Electrons present in this band take part in the conduction of current.

Forbidden band or band gap

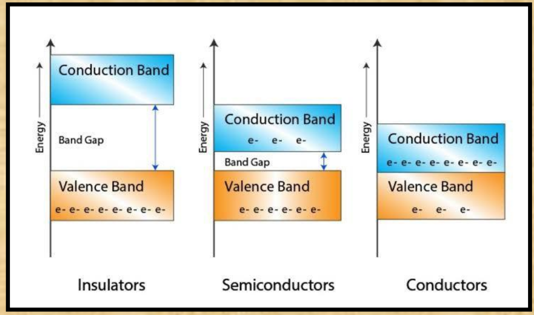
This band is completely empty. The minimum energy required to shift an electron from valence band to conduction band is called band gap.

Classification of solids on the basis of energy bands

1) **Conductors:** When valence bands and conduction band overlap each other, these are considered as conductors.

2) **Semiconductors:** When valence bands and conduction bands are separated by a small energy gap these are considered as semiconductors.

3) **Insulators:** When valence bands and conduction bands are separated by a large energy gap these are considered as insulators.


Conduction Band
Band Gap
Valence Band
e- e- e- e- e- e- e- e-
Energy
Insulators
Conduction Band
e- e- e-
Band Gap
Valence Band
e- e- e- e- e- e-
Energy
Semiconductors
Conduction Band
e- e- e- e- e- e- e- e-
Valence Band
e- e- e-
Energy
Conductors

Intrinsic and extrinsic semiconductor

Semiconductors are classified on the basis of their purity as –:

1. Intrinsic (pure)

2. Extrinsic (impure)

➢ Intrinsic semiconductor

It is a pure semiconductor without any significant dopant species present

$$n_e = n_h = n_i$$

where, n_e= number densities of e^- and

n_h = number of densities of holes

n_i = intrinsic carrier concentration.

An intrinsic semiconductor is also called an undoped semiconductor or i-type semiconductor.

➢ Extrinsic semiconductor

Pure semiconductor when doped with the impurity, it is known as extrinsic semiconductor.

Extrinsic semiconductors are basically of two types:

(a) n-type semiconductors.
(b) p-type semiconductors
NOTE: Both type of semiconductors are electrically neutral.

➢ Doping

"The process in which some atoms of a pure or intrinsic semiconductor are replaced by impurity atoms from their lattice-sites is called doping."

The impurity so added is called ***dopant***. Doping is the process of introducing an impurity into a semiconductor. During the production of extrinsic semiconductors, the amount and kind of impurity to be introduced to the material must be carefully monitored.

➢ n – type semiconductor

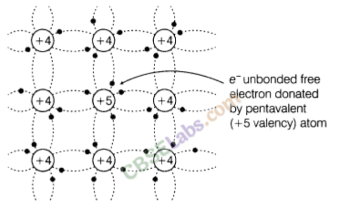
Majority charge carriers are electrons and minority charge carriers are holes, $\Rightarrow n_e > n_h$.

Here, we dope Si or Ge with a pentavalent element,

Then four of its electrons bond with the four silicon neighbours,

While fifth remains very weakly bound to its parent atom.

Formation of n-type semiconductor is shown below:


+4
+4
+4
+4
+5
+4
+4
+4
+4
e⁻ unbonded free electron donated by pentavalent (+5 valency) atom

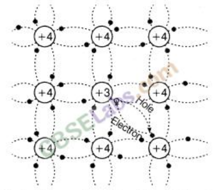
Pentavalent donar atom (As, Sb, P, etc.) doped for tetravalent Si or Ge giving -type

➢ p – type semiconductor

Majority charge carriers are holes and minority charge carriers are eletron $\Rightarrow n_h > n_e$.

In a p-type semiconductor, doping is done with trivalent impurity atoms, i.e. those atoms which have 3 valence electrons in their valence shell.

Formation of p - type semiconductor is shown below:



Trivalent acceptor atom (In, Al, B, etc) doped in tetravalent Si or Ge lattice giving *p*-type semiconductor

➢ *p – n junction*

The p – n junction is formed between the p-type and n-type semiconductors.

"A p – n junction is an interface or a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor."

In a semiconductor, the p – n junction is created by the method of doping.

- The p-side or the positive side of the semiconductor has an excess of holes,
- The n-side or the negative side has an excess of electrons.

➢ *Terms related to p – n junction*

1) **Depletion Layer:** At p-n junction a region is created, where there is no charge carriers. This region is called depletion layer. The width of this region is of the order of 10^6 m.

2) **Potential Barrier:** The potential difference across the depletion layer is called potential barrier. Barrier potential for Ge is 0.3 V and for Si is 0.7 V.

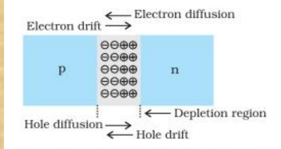
3) **Forward Biasing (diffusion):** In this biasing, the p -side is connected to positive terminal and n-side to negative terminal of a battery. In this biasing, forward current flows due to majority charge carriers. The width of depletion layer decreases.

4) **Reverse Biasing (drift):** In this biasing, the p-side is connected to negative terminal and n-side to positive terminal of a battery. In this biasing, reverse current flows due to minority charge carriers. The width of depletion layer increases. A p-n junction diode can be utilized as a rectifier.

➢ *formation of p – n junction*

During formation of p-n junction, due to the concentration gradient across p and n sides, holes diffuse from p-side to n-side (p —> n) and electrons diffuse from n-side to p-side (n —> p).

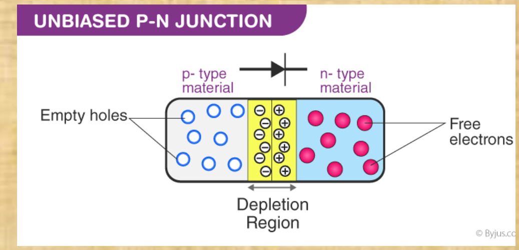
This space charge region on either side of the junction together is known as depletion region. Depletion region is free from mobile charge carriers. Width of depletion region is of the order of 10^{-6} m. The potential difference developed across the depletion region is called the **potential barrier**.



p-n junction formation process.

➢ *Unbiased p – n junction*

In an unbiased p-n junction, there is no applied emf across the diode and hence no current flows due to minority or majority carriers.


UNBIASED P-N JUNCTION
p- type material
n- type material
Empty holes
Free electrons
Depletion Region
© Byjus.co

➢ *Biased p – n junction*

∗ Biasing Conditions for the P-N Junction Diode –:

There are two operating regions in the P-N junction diode:

- P-type
- N-type

There are three biasing conditions for the P-N junction diode, and this is based on the voltage applied:

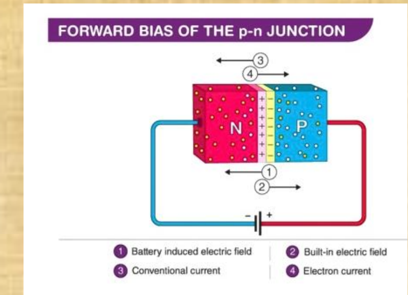
1. **Zero bias:** No external voltage is applied to the p - n junction diode.

2. **Forward bias:** The positive terminal of the voltage potential is connected to the p-type while the negative terminal is connected to the n-type.

3. **Reverse bias:** The negative terminal of the voltage potential is connected to the p-type and the positive is connected to the n-type.

➢ *Forward bias*

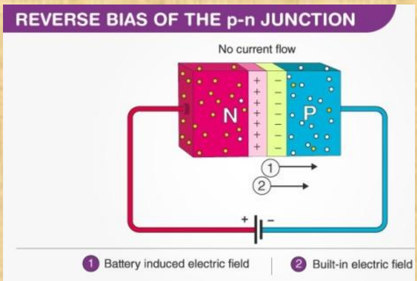
In this biasing, the p -side is connected to positive terminal and n-side to negative terminal of a battery. In this biasing, forward current flows due to majority charge carriers. The width of depletion layer decreases.


FORWARD BIAS OF THE p-n JUNCTION
3
4
N
P
1
2
–
+
1 Battery induced electric field
2 Built-in electric field
3 Conventional current
4 Electron current

➢ *Reverse bias*

In this biasing, the p-side is connected to negative terminal and n-side to positive terminal of a battery. In this biasing, reverse current flows due to minority charge carriers.

- The width of depletion layer increases. A p-n junction diode can be utilized as a rectifier.
- Zener diode, photo-diode, light-emitting diode, etc are specially designed p-n junction diodes.


REVERSE BIAS OF THE p-n JUNCTION
No current flow
N
P
1
2
+
–
1 Battery induced electric field
2 Built-in electric field

➢ *p – n junction formula*

The formula used in the P-N junction depends upon the built-in potential difference created by the electric field is given as:

$$\boxed{\mathbf{E_0 = V_T} \mathit{ln} \left[\frac{\mathbf{N_D.N_A}}{\mathbf{n_i^2}}\right]}$$

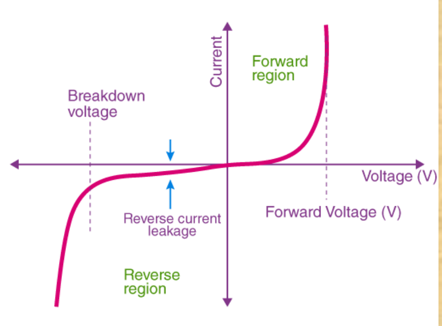
Where,

- E_0 is the zero bias junction voltage.
- V_T is the thermal voltage of 26mV at room temperature.
- N_D and N_A are the impurity concentrations
- n_i is the intrinsic concentration.

➢ *V- I characteristics of p-n junction*

V - I characteristics of P-N junction diodes is a curve between the voltage and current through the circuit.

Voltage is taken along the x-axis while the current is taken along the y-axis. The graph given below is the V-I characteristics curve of the P-N junction diode.



➢ *Applications of p – n junction*

- P-N junction diode can be used as a photodiode as the diode is sensitive to the light when the configuration of the diode is reverse-biased.
- It can be used as a solar cell.
- When the diode is forward-biased, it can be used in LED lighting applications.
- It is used as rectifier in many electric circuits and as a voltage-controlled oscillator in varactors.

➢ *Types of diode*

There are different types of semiconductor diodes that are used widely in our daily life some of which are,

- LED
- Zener Diode
- Photodiode
- Solar cell

➢ *LED*

LED is also called a Light Emitting Diode, it is the most useful kind of diode when the diode is attached in forwarding bias, the then-current that flows through the junction produces light and hence they are widely used as bulbs for providing light.

➢ Zener diode

Zener diode is a type of diode, that allows the flow of current in a forward direction, and it can also work in reverse conditions, the Zener diode has an application in voltage regulation, The Zener diode is a heavily doped p-n junction diode made to work in reverse bias condition.

➢ photo diode

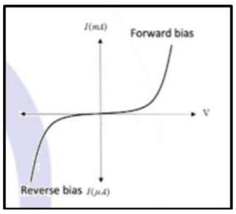
A photodiode is a PN-junction diode that consumes light energy to produce an electric current. They are also called a photo-detector, a light detector, and a photo-sensor.

Photodiodes are designed to work in reverse bias condition. Typical photodiode materials are Silicon, Germanium and Indium gallium arsenide.

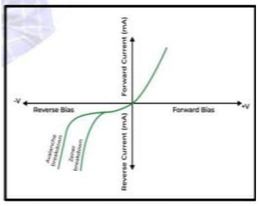
➢ Solar cell

A solar cell is a p-n junction diode in its most basic form. Solar cells are a type of photoelectric cell, which is defined as a device whose electrical properties such as current, voltage, or resistance, change when exposed to light.

➢ I – V Characteristic



LED



ZENER DIODE

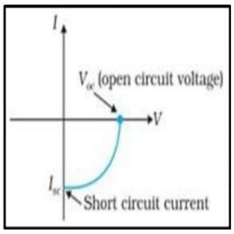
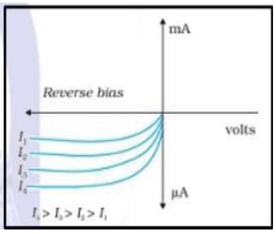


PHOTO DIODE



SOLAR CELL

➢ Transistors

"A junction transistor is a semiconductor device having two junctions and three terminals."

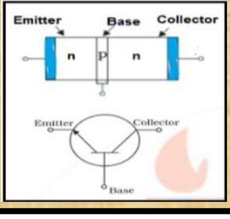
The transistor has three doped regions forming two p-n junctions.

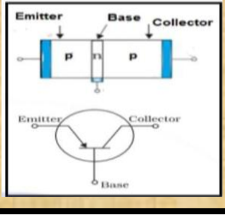
There are two types of transistors:

a) n-p-n transistor

b) p-n-p transistor

The schematic representation and symbols of the two transistors are given below:





Transistors

The 3 layers are – Emitter, Base and Collector.

1. **Emitter** – It is the left hand side thick layer of transistor which is heavily doped. This supplies a large number of majority carriers for the current flow through the transistor.

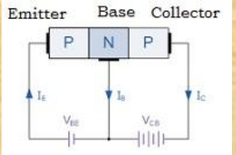
2. **Base** – It is the thin, central segment which is lightly doped.

3. **Collector** – It is the right hand side thick layer of transistor which is moderately doped. This segment collects a major portion of the majority carriers supplied by the emitter.

- **Depletion region**: The depletion regions are formed at the emitter-base junction and the base-collector junction.

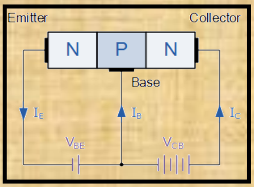
p-n-p transistor

Circuit Diagram:



p-n-p transistor

Circuit Diagram:



From the circuit, we find $I_E = I_B + I_C$.

Transistor configuration

The possible configurations of transistor are:

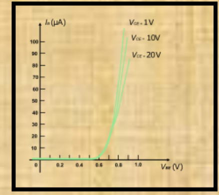
a) **Common Base configuration:** The base of the transistor is common to both the input and the output.

b) **Common Emitter configuration:** The emitter of the transistor is common to both the input and the output.

c) **Common Collector configuration:** The collector of the transistor is common to both the input and the output.

Transistor characteristics

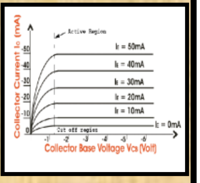
∗ Input transistor characteristics



"The variation of base current I_B with base – emitter voltage V_{BE} is called input characteristics."

$R_i = \delta V_{BE} / \delta I_B$ when V_{CE} is constant

∗ Output transistor characteristics



"The variation of collector current I_C with collector – emitter voltage V_{CE} is output characteristics."

$R_i = \delta V_{CE} / \delta I_C$ when I_B is constant

Question - Answers

① MCQs

1. What bonds are present in a semiconductor?

(A) Monovalent (B) Bivalent (C) Trivalent (D) Covalent

Answer: **(D) Covalent**

2. The number of electrons in the valence shell of a semiconductor is

(A) 1 (B) 2 (C) 3 (D) 4

Answer: **(D) 4**

3. What happens to the forbidden energy gap of a semiconductor with the fall of temperature?

(A) Decreases
(B) Increases
(C) Unchanged
(D) Sometimes decreases and sometimes increases

Answer: **(B) Increases**

4. In a p-type semiconductor, the current conduction is due to:

(A) Holes (B) Atoms (C) Electrons (D) Protons

Answer: **(A) Holes**

5. What is the main function of a transistor?

(A) Simplify (B) Amplify (C) Rectify (D) All of the above

Answer: **(B) Amplify**

6. A p-type semiconductor is obtained when we dope pure silicon impurity with some atoms of the element of the: **[PYQ NIOS Jan 2021]**

(A) 3rd group of periodic table
(B) 4th group of periodic table
(C) 5th group of periodic table
(D) 6th group of periodic table

Answer: **(A) 3rd group of periodic table**

7. In a semiconductor, what is responsible for conduction?

(A) Electrons only
(B) Holes only
(C) Both electrons and holes
(D) Neither electrons nor holes

Answer: **(C) Both electrons and holes**

8. What happens to the resistance of semiconductors on heating?

(A) Increases
(B) Decreases
(C) Remains the same
(D) First increases later decrease

Answer: **(B) decreases**

9. In intrinsic semiconductors at room temperature, the number of electrons and holes are:

(A) Unequal (B) Equal (C) Infinite (D) Zero

Answer: **(B) Equal**

10. A p-type semiconductor is:

(A) Positively charged (B) Negatively charged
(C) Uncharged (D) None of the above

Answer: **(C) Uncharged**

11. In semiconductors at room temperature, which of the following is likely to happen?

(A) The valence band is partially empty and the conduction band is partially filled
(B) The valence band is filled and the conduction band is partially filled
(C) The valence band is filled
(D) The conduction band is empty

Answer: **(A) The valence band is partially empty and the conduction band is partially filled**

12. In a n-p-n transistor in common emitter configuration, the base current I_b = .001 mA and collector current I_c = 1mA. The current gain will be ___

(A) 1000
(B) more than 1000
(C) less than 1000 but not less than 100
(D) less than 100 **[PYQ NIOS Jan 2021]**

Answer:

13. Barrier potential of a P-N junction diode does not depend on:

(A) doping density (B) diode design
(C) temperature (D) forward bias

Answer: **(B) diode design**

14. The junction diode whose I-V characteristics lie in the fourth quadrant of the coordinate axis is: **[PYQ NIOS Jan 2021]**

(A) Zener diode (B) Light Emitting diode
(C) Photo diode (D) Solar cell

Answer: **(C) Photo diode**

15. Forward biasing is that in which applied voltage:

(A) increases potential barrier
(B) cancels the potential barrier
(C) is equal to 1.5 volt
(D) None of these

Answer: **(B) cancels the potential barrier**

16. When p-n junction diode is forward biased then

(A) both the depletion region and barrier height are reduced
(B) the depletion region is widened and barrier height is reduced
(C) the depletion region is reduced and barrier height is increased
(D) Both the depletion region and barrier height are increased

Answer: **(A) both the depletion region and barrier height are reduced**

17. In a p-n junction diodes, the depletion layer has high resistance, because it contains:

(A) No charge carriers

(B) Large number of charge carrier
(C) Only electrons as charge carrier
(D) Only holes as charge carrier **[PYQ NIOS April 2022]**

Answer: (A) No charge carriers

18. What is the resistivity of a pure semiconductor at absolute zero?
(A) Zero
(B) Infinity
(C) Same as that of conductors at room temperature
(D) Same as that of insulators at room temperature

Answer: (B) Infinity

19. In a reverse biasing of p-n junction, the width of depletion layer:
(A) Increases (B) Decreases
(C) Decreases upto a certain value and then increases
(D) Remains unchanged **[PYQ NIOS April 2022]**

Answer: (A) Increases

20. Find out the application of the diode:
(A) Oscillator (B) Amplifier (C) Rectifier (D) Modulator

Answer: (C) Rectifier

21. Which of the following is a transistor material?
(A) Chip (B) Insulator (C) Semiconductor (D) Metal

Answer: (C) Semiconductor

22. What causes drift current in a p-n junction diode?
(A) Electric field
(B) Charge carriers density
(C) Collision of electrons
(D) Electric potential

Answer: (B) Charge carriers density

23. The part of a transistor which is heavily doped to produce a large number of majority carriers is:

(A) base (B) emitter (C) collector (D) None of these

Answer: **(B) emitter**

24. For a common base amplifier, the values of resistance gain and voltage gain are 3000 and 2800 respectively. The current gain will be:

(A) 1.1 (B) 0.98 (C) 0.93 (D) 0.83

Answer: **(C) 0.93**

25. To obtain a P – type Si semiconductor, we need to dope pure Si with:

(A) Aluminium (B) Phosphorous

(C) Oxygen (D) Germanium

Answer: **(A) Aluminium**

②Complete the sentence by using an appropriate word:

26. **p – type, insulator, reverse, n – type, electrons, forward, doping , rectification, increases**

{NOTE: Some of the above written words are extra, they are only for the confusion.}

1. In an n-type semiconductor, the majority charge carriers are ________

2. The process of adding impurity atoms to a pure semiconductor is known as ________.

3. A p-n junction diode allows current to pass through it in the ________ bias condition.

4. The type of semiconductor in which electrons are the majority carriers is called ________.

5. At absolute zero temperature, a pure semiconductor behaves like a/an ________.

6. The type of semiconductor in which holes are the majority carriers is called ________.

Answer: **(1) electrons, (2) doping, (3) forward, (4) n – type, (5) insulator, (6) p – type**

27. **Band gap, conductor, acceptor, reverse breakdown, semiconductor, rectification, insulator, electrons, donor, forward**

{NOTE: Some of the above written words are extra, they are only for the confusion.}

1. A semiconductor is a material whose electrical conductivity lies between that of a **……………..** and a **………………**.

2. The energy gap between the valence band and the conduction band in a semiconductor is called the **………………**.

3. The process by which a p-n junction diode converts alternating current (AC) into direct current (DC) is called **………………**.

4. A Zener diode is designed to operate in the **……………..** region.

5. In an n-type semiconductor, the impurity atoms added are called **……………..**

6. In a p-type semiconductor, the impurity atoms added are called **……………..** .

Answer: **1. conductor, insulator, 2. band gap, 3. rectification, 4. reverse breakdown, 5. donor, 6. acceptors**

③Fill in the blanks:

28.

1. The type of semiconductor device that can be used as an electronic switch is called a ……………….
2. The width of the depletion region in a p-n junction diode ……………… when it is reverse biased.
3. The current amplification factor of a common-emitter transistor configuration is denoted by ……………….
4. In a photo-diode, the reverse current is directly proportional to the ……………… of incident light.
5. In a transistor, the region between the emitter and the collector is called the ……………….

Answer: **1. Transistor, 2. Increases, 3. Beta, 4. Intensity, 5. Base**

29.

1. A semiconductor with equal electron and hole concentrations is known as a/an ……………… semiconductor.
2. The movement of charge carriers under the influence of an electric field in a semiconductor is called ……………….
3. The impurity atoms that provide extra electrons in an n-type semiconductor are called ……………….
4. The device used to store electric charge in a circuit and made from a p-n junction is called a ……………… .

Answer: **1. Intrinsic, 2. Drift, 3. Donor atoms, 4. Capacitor**

④Match the following:

30. Match the statements given in COLUMN A with the appropriate statement of COLUMN B.

COLUMN A	COLUMN B
1. p-type Semiconductor	**A.** Decreased width of depletion region
2. n-type Semiconductor	**B.** Increased width of depletion region
3. Forward Bias	**C.** Electrons as majority carriers
4. Reverse Bias	**D.** Holes as majority carriers

Answer: **1 – D, 2 – C, 3 – A, 4 – B**

31. Match the statements given in COLUMN A with the appropriate statement of COLUMN B.

COLUMN A	COLUMN B
1. Light emitting diode	**A.** Generates current when exposed to light
2. Photo diode	**B.** Emission of light when current flows through
3. Zener diode	**C.** Conducts in reverse breakdown region

Answer: **1 – B, 2 – A, 3 – C**

⑤True or false:

32. In an intrinsic semiconductor, the number of electrons is equal to the number of holes.

⇒True

33. LEDs can emit light of different colors depending on the material used in the semiconductor.

⇒ True

34. The energy band gap of a conductor is smaller than that of a semiconductor.

⇒ False

35. A transistor can be used as an amplifier or a switch.

⇒ True

36. At absolute zero temperature, a semiconductor acts as a conductor.

⇒ False

37. Photodiodes are always operated in reverse bias.

⇒ True

38. The base region of a transistor is lightly doped compared to the emitter and collector regions.

⇒ True

39. Forward biasing of p-n junction diode offers high resistance.

⇒ False

40. Increasing the temperature of a semiconductor decreases its conductivity.

⇒ False

41. In an n-type semiconductor, holes are the majority charge carriers.

⇒ False

42. The width of the depletion region in a p-n junction diode decreases when forward biased.

⇒ True

43. Doping a semiconductor with a pentavalent impurity creates a p-type semiconductor.

⇒ False

44. Zener diodes are designed to operate in the breakdown region.

⇒ True

45. In a photo-diode, the reverse current is directly proportional to the intensity of incident light.

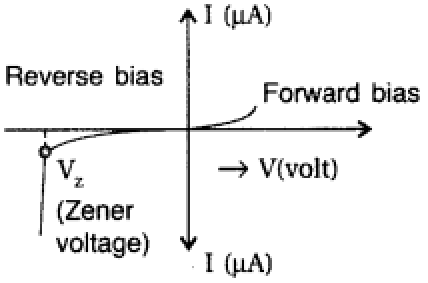
⇒ True

⑥Very short type answer question [2 marks each]:

46. Name the semiconductor device that can be used to regulate an unregulated dc power supply. With the help of I-V characteristics of this device, explain its working principle.

Answer:

Name: Zener diode is used to regulate an unregulated dc power supply.



V-I charactertic

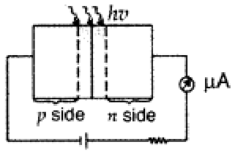
Working principle: When a zener diode is operated in the reverse break down region, the voltage across it remains practically constant (equal to the break down voltage V-I) for a large change in the reverse current.

47. Give reason, why, a p-type semiconductor crystal is electrically neutral although $n_h >> n_e$?

Answer: In a p-type semiconductor, the trivalent impurity atom shares its three valence electrons with the three tetravalent host atoms while the fourth bond remains unbounded. The impurity atom as a whole is electrical neutral. Hence the p-type semiconductor is also neutral.

48. Draw the circuit diagram of an illuminated photodiode in reverse bias. How is photodiode used to measure light intensity?

Answer: A measurement of the change in the reverse. saturation current on illumination can give the values of light intensity because photocurrent is proportional to incident light intensity.



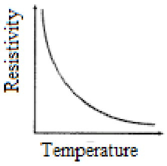
A reverse biased photodiode illuminated with light.

49. How is the conductivity of a semiconductor affected with the increase in its temperature? Explain. [PYQ NIOS Jan 2021]

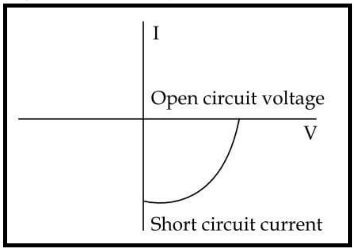
Answer: As the temperature increases, more electrons get the energy to jump from Conduction band to valence band, and thereby increases the conductivity of the semiconductor.

50. Draw a graph showing the variation of resistivity of a semiconductor with temperature. [PYQ NIOS Oct 2021]

Answer: The resistivity of a semiconductor is exponentially decreases with the temperature. So, the resistivity vs temperature graph will be as shown in figure.



51. **The figure shows the V-I characteristics of a semiconductor diode designed to operate under reverse bias.**



a. **Identify the semiconductor diode.**
b. **How does the separation of electrons and holes takes place in this semiconductor diode?** **[PYQ NIOS Oct 2022]**

Answer:

52. **If the emitter and base of npn transistor have same doping concentration, explain how will the collector and base current be affected?** **[PYQ NIOS Oct 2022]**

Answer: If the base region of a transistor is doped equally to that of emitter region, then a large electron hole recombination will take place in base, due to it, the base current would increase but collector current would decrease. Then the very purpose of a transistor would be defeated.

53.

(a) What is the function of a photodiode?
(b) What is the function of Zener diode ?

Answer:

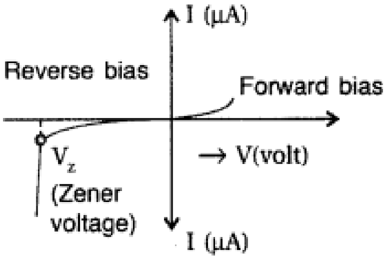
(a) A photodiode is a special purpose p-n junction diode fabricated with a transparent window to allow light to fall on diode. It is operated under reverse bias.

(b) A diode is a semiconductor device that essentially acts as a one-way switch for current. It allows current to flow easily in one direction, but severely restricts current from flowing in the opposite direction.

54. **Name the semiconductor device that can be used to regulate an unregulated dc power supply. With the help of I-V characteristics of this device, explain its working principle.**

Answer:

Name : Zener diode is used to regulate an unregulated dc power supply.

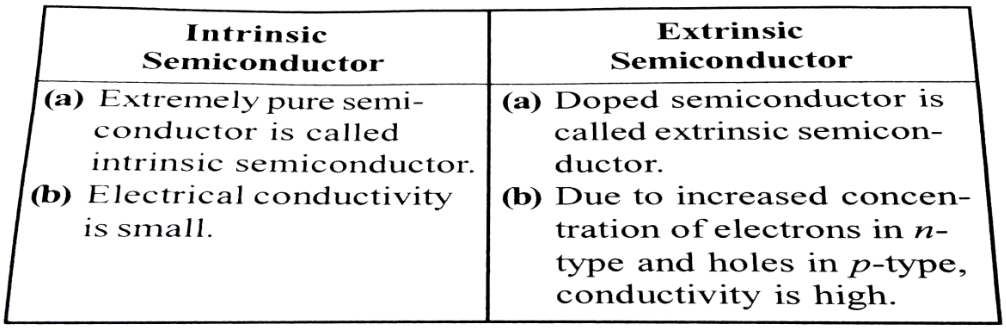


V-I charactertic

Working principle: When a zener diode is operated in the reverse break down region, the voltage across it remains practically constant (equal to the break down voltage V-I) for a large change in the reverse current.

55. **Distinguish between the intrinsic and extrinsic semiconductor.**

Answer:



Intrinsic Semiconductor	Extrinsic Semiconductor
(a) Extremely pure semiconductor is called intrinsic semiconductor. **(b)** Electrical conductivity is small.	**(a)** Doped semiconductor is called extrinsic semiconductor. **(b)** Due to increased concentration of electrons in n-type and holes in p-type, conductivity is high.

⑦Short type answer question [3 marks each]:

56. How is forward biasing different from reverse biasing in a pn junction diode?

Answer:

Forward biasing: If the positive terminal of a battery is connected to a p-side and the negative terminal to the 72-side, then the p-n junction is said to be forward biased. Here the applied voltage V opposes the barrier voltage VB. As a result of this

- the effective resistance across the p-n junction decreases.
- the diffusion of electrons and holes into the depletion layer which decreases its width.

Reverse biasing: If the positive terminal of a battery is connected to the 72-side and negative terminal to the p-side, then the p-n junction is said to be reverse biased.
The applied voltage V and the barrier potential V_B are in the same direction. As a result of this

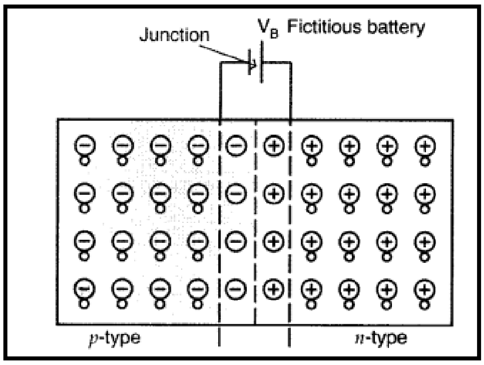
- the resistance of the p-n junction becomes very large.
- the majority charge carriers move away from the junction, increasing the width of the depletion layer.

57. Explain how a depletion region is formed in a junction diode.

Answer:

As soon as a p-n junction is formed, the majority charge carriers begin to diffuse from the regions of higher concentration to the regions of lower concentrations. Thus the electrons from the n-region diffuse into the p-region and where they combine with the holes and get neutralised.

Similarly, the holes from the p-region diffuse into the n-region where they combine with the electrons and get neutralised. This process is called electron-hole recombination.



The p-region near the junction is left with immobile -ve ions and n-region near the junction is left with +ve ions as shown in the figure. The small region in the vicinity of the junction which is depleted of free charge carriers and has only immobile ions is called the depletion layer.

In the depletion region, a potential difference VB is created, called potential barrier as it creates an electric field which opposes the further diffusion of electrons and holes.

(i) In forward biased, the width of depletion region is decreased.

(ii) In reverse biased, the width of depletion region is increased.

58. Explain how an intrinsic semiconductor can be converted into a (i) n-type semiconductor and (ii) p-type semiconductor. Give one example of each and their energy band diagrams. [PYQ NIOS Jan 2021]

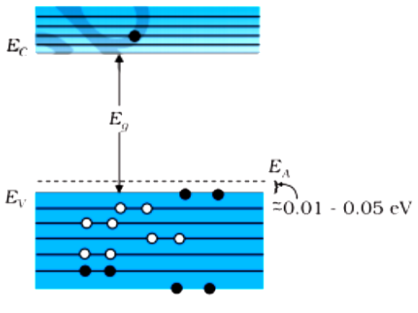
Answer:

Semiconductors in which the number of electrons ne is equal to the number of holes n_h are intrinsic semiconductors. When a small amount of suitable impurity is added to the intrinsic semiconductor we can convert it into an extrinsic semiconductor of either p-type or n-type. Doping changes the concentration of charge carriers in the element.

(i) P- type: When Si or Ge is doped with any trivalent impurity like Al, B etc we get a p-type semiconductor. The dopant has one valence electron less. Thus, this atom form covalent bond with the neighbouring three atoms and, is less of one electron to offer to the fourth silicon atom and as a result there is a vacancy. Hence, an electron in the outer orbit of the neighbouring atom may jump to fill this vacancy leaving a vacancy or hole at it's own site.

This hole is the conducting charge carrier. Therefore, doping with a trivalent impurity gives us p-type semiconductor.

Energy band diagram for a p-type semiconductor is as shown below:

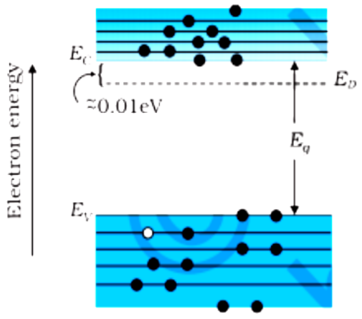


(b) $T > 0K$

(ii) n - type: When we dope Si or Ge with pentavalent impurities like As, P then four electrons of this atom will form covalent bonds with the neighbouring Si atom in the lattice. Whereas, the fifth electron will remain loosely bound to it's parent atom. Hence, the ionisation energy which is required to make this electron free is very less and it will move around even in room temperature.

Thus, the pentavalent dopant will donate one extra electron for conduction and this acts as an n-type semiconductor.

Energy band diagram for n-type semiconductor is as shown below:



(a) $T > 0K$

59. Mention the important considerations required while fabricating a p-n junction diode to be used as a Light Emitting Diode (LED). What should be the order of band gap of an LED if it is required to emit light in the visible range?

Answer:

The important considerations required while fabricating a p-n junction diode to be used as a Light Emitting Diode (LED) are :

(i) The Light Emitting efficiency is maximum.

(ii) The reverse breakdown voltage of LEDs are very low. Care should be taken that high reverse voltages do not appear across them.

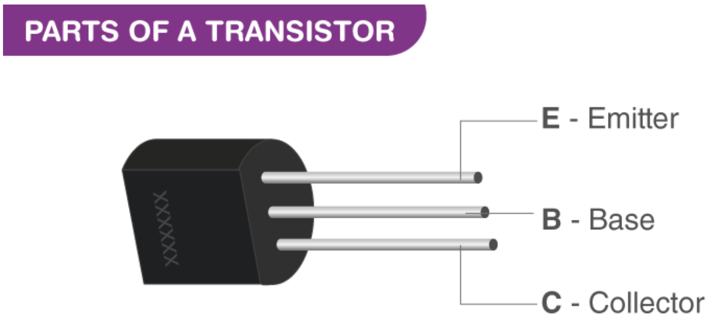
The semiconductor used for fabrication of visible, LEDs must have a band gap of 1.8 eV (spectral range of visible light is from about 0.4 µm to 0.7 µm i.e. from about 3 eV to 1.8 eV).

60.

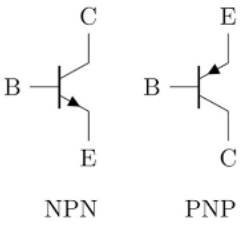
(A) Show three basic components of a Transistor with the help of a diagram.
(B) Draw symbols of n-p-n and p-n-p transistors.
(C) Why does the arrow head point ‘outward’ in case of n-p-n transistor; while ‘inward’ in case of p-n-p transistor? **[PYQ NIOS Oct 2021]**

Answer:

(A) Three basic components of a transistor:



(B) Symbols of n-p-n and p-n-p transistors:



(C) The arrow denotes the flow of current. B is for base. C is for collector. E is for emitter.

We can interpret that arrow in a couple ways: it's the direction of positive current flow (opposite of electron flow), and also as pointing toward the lower voltage when the transistor is switched on, i.e. for an NPN the emitter has to be at a lower voltage than the base/collector in order for it to conduct, whereas for a PNP it has to be higher.

61. A transistor is designated as AC 125, what does this signify? Name the three configuration in which a transistor can be used draw a circuit diagram with proper biasing showing a n-p-n transistor common base configuration. [PYQ NIOS April 2022]

Answer: The designation "AC 125" for a transistor signifies its type and specifications. The "AC" usually represents the manufacturer's name or code, and "125" is the specific model number of the transistor.

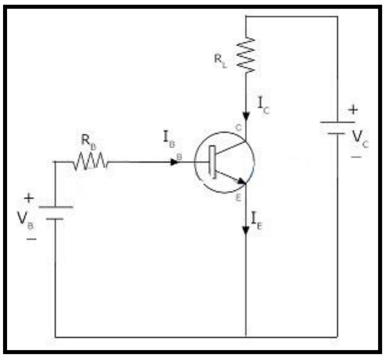
Transistors can be used in three basic configurations: Common Emitter (CE), Common Base (CB), and Common Collector (CC).

Drawing a circuit diagram of an NPN transistor in the Common Base configuration with proper biasing:

NPN Transistor Common Base Configuration

In the Common Base (CB) configuration:

The base terminal (B) is the input terminal. The emitter terminal (E) is the output terminal. The collector terminal (C) is common between input and output.



Biasing:

- ○ The emitter-base junction is forward-biased (E > B), allowing current to flow from emitter to base.
- ○ The collector-base junction is reverse-biased (C < B), preventing significant current flow from collector to base.

- This configuration provides a low input impedance and high output impedance. It is often used in high-frequency applications, amplifiers with low voltage gain, and impedance matching circuits.

⑧Long type answer question [5 marks each]:

62.

(a) Classify solids as conductors, semiconductors and insulators, on the basis of energy bands. Draw one diagram each for their energy bands.

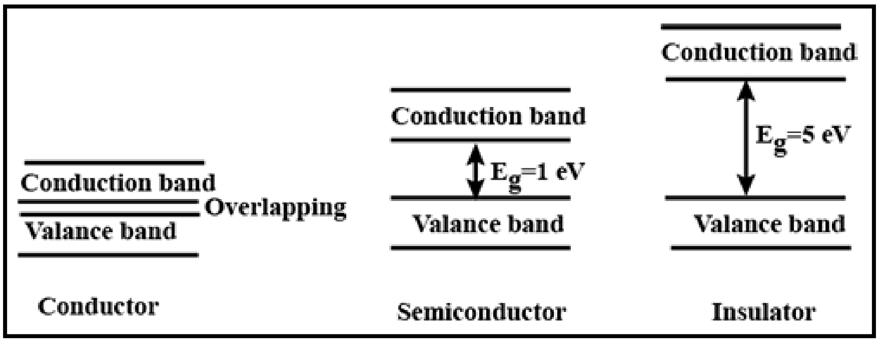
(b) Write down main two differences between intrinsic and extrinsic semiconductors. **[PYQ NIOS Oct 2021]**

Answer:

(a) solids are classified on the basis of energy bands nto three parts:

1. conductors
2. Semiconductors
3. Insulators

- In conductors, both the valance band and conduction band overlap each other. So there is zero band gap in a conductor.
- In semiconductor, there is a small band gap approximately of 1 eV.
- In an insulator, there is a large band gap of nearly 5 eV.


Conduction band
Valance band
Overlapping
Conductor
Conduction band
E_g=1 eV
Valance band
Semiconductor
Conduction band
E_g=5 eV
Valance band
Insulator

(b) differences between intrinsic and extrinsic semiconductors are:

Intrinsic semiconductor	Extrinsic semiconductor
1. These are pure semiconductors	(a) These are doped semiconductors
2. Charge carriers are equal in numbers when biased	(b) Charge carriers are unequal in numbers when biased
3. Electrical conductivity is less	(c) Electrical conductivity is more.

63.

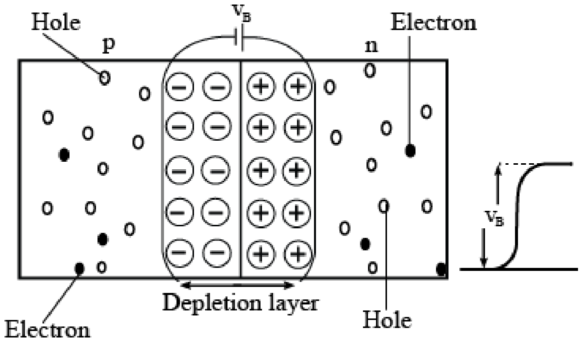
(a) Explain the formation of p-n junction. Draw a diagram for it. Hence define 'Depletion Region' and 'Barrier Potential'.

(b) Draw I-V characteristics for a zener diode. What is its main application ?

[PYQ NIOS Oct 2021]

Answer:

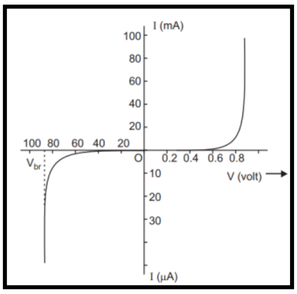
(a) During the formation of p-n junction, the holes diffuse from p-type semiconductor to the n-type, and electrons diffuse from n-type to p-type. This is because of the concentration gradient across p-side and n-side.



When a hole diffuses from p to n type, it leaves an unmovable negative charge. Similarly, when an electron diffuses from n to p type, it leaves an unmovable positive charge.

When the diffusion of holes and electrons takes place continuously across the junction, a layer of unmovable positive and negative charges are developed on either side of the junction. This layer is called the depletion layer or the depletion region and the potential difference across the region is called the barrier potential.

(b) I-V characteristics for a zener diode is:



Applications and Uses of Zener Diode can be seen in the following:

- As a voltage regulator
- Protects from overvoltage
- Used in clipping circuits
- Used to shift voltage

Since the voltage drop across the diode remains constant over a wide range of voltages, the zener diode is suitable for voltage regulation.

1. Zener diode acts as a voltage regulator

When the load voltage equals the breakdown voltage, the resistors which are connected in series limit the current through the diode when there is an excess amount of voltage while the diode is conducting. While doing that the diode generates some kind of noise which can be suppressed by adding a large value decoupling capacitor across the diode.

2. Zener diode as a voltage regulator

Zener diode protects from over voltage

When the input voltage increases and reaches the Zener breakdown voltage, the current through the diode will create a voltage drop across the resistor. This triggers a short circuit to the ground.

3. Zener diode is used in clipping circuits

Clipper circuits are used to prevent the output signal from going beyond a determined value without changing anything of the input signal. Uses of zener diode include modifying and shaping the AC waveform clipping circuits.

4. **Zener diode can be used to shift voltage**

Zener diode's core uses include converting a signal from one voltage to another. It has the ability to maintain a steady output voltage in the breakdown region. This voltage shifting functionality makes zener diode an ideal component of the operation. These were some uses of zener diode.

64.

(a) Draw a circuit diagram of npn common emitter transistor as an amplifier showing waveforms of signal voltage and output voltage.

(b) Obtain the expression for the voltage gain of a transistor amplifier in common emitter configuration in terms of the load resistance RL, current gain βa and input resistance.

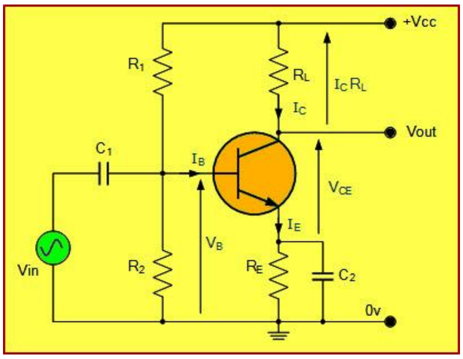
(c) Explain why are the input and output voltages are in opposite phase ?

(d) Why is a npn transistor preferred over a pnp transistor ?

[PYQ NIOS Oct 2022]

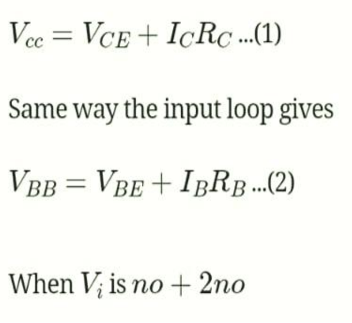
Answer:

(a) a circuit diagram of npn common emitter transistor as an amplifier showing waveforms of signal voltage and output voltage.



(b) Applying Kirchhoff's law to the out put loop.

We get



$V_{cc} = V_{CE} + I_C R_C$ ...(1)

Same way the input loop gives

$V_{BB} = V_{BE} + I_B R_B$ ...(2)

When V_i is $no + 2no$

$$V_{BE} + V_i = V_{BE} + I_B I_B + \Delta I_B (R_B + V_i)$$

$$V_i = \Delta I_B (R_B + r_i)$$

$$= r \Delta I_B$$

The change in I_B causes a change in I_C. We define a parameter B_{AC}

$$B_{ac} = \frac{\Delta I_C}{\Delta I_B} = \frac{i_C}{l_B}$$

(Current gain A)

The change in I_C due to a change in I_B can a change in V_{CE} and the voltages drop across the resistor R_i because V_{CC} is fixed.

These changes can be given by eqn 1 as

$$\Delta V_{CC} = \Delta V_{CE} + R_C \Delta I_C = O$$

$$\Delta V_{CE} = R_C \Delta I_C$$

The change in V_{CE} is the output voltage V_O

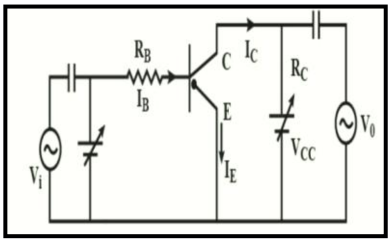
$$V_0 = \Delta V_{CE} = -B_{ac} R_L \Delta I_B$$

Voltage gain

$$A_V = \frac{V_0}{V_i} = \frac{\Delta_{CE}}{r \Delta I_B}$$

$$A_v = \frac{-\beta_{AC} \times R_L}{r}$$

(c) –ve sign mass output voltage is opposite with phase with the input voltage



(d) A n-p-n transistor has electrons as majority charge carriers whereas the p-n-p transistor has holes as the majority charge carriers. The mobility of electrons is better than the mobility of holes. Mobility of electrons is more than hole, so as a result n-p-n transistors are faster than p-n-p that's why they are preferred.

65.

(a) With the help of the circuit diagram explain how does a p-n junction diode behave in

(i) forward bias and

(ii) reverse bias

(b) Draw the V-I Characteristics curve for p-n junction diode for forward bias and reverse bias. **[PYQ NIOS Oct 2022]**

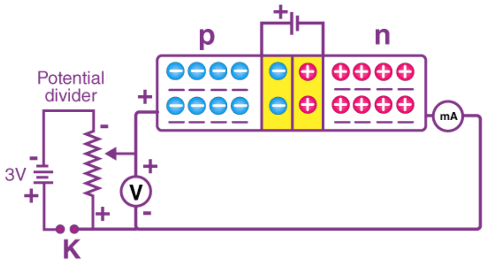
Answer:

(a) Referring to the characteristic curve,

(i) The VI characteristic curve of p-n junction diode in forward biased is non linear.

The current first increases slowly, almost negligibly, till the voltage across the diode crosses a certain value.

After the characteristic voltage, the diode current increases significantly,even for a very small increase in the diode bias voltage. This voltage is called THRESHOLD VOLTAGE or CUT-IN voltage.



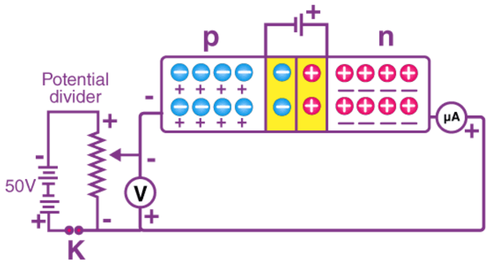
P-N Junction Diode in Forward Bias

(ii) The p-type of the p-n junction is attached to the negative terminal of the external voltage, while the n-type is connected to the positive terminal.

As a result, the potential barrier at the intersection is enhanced.

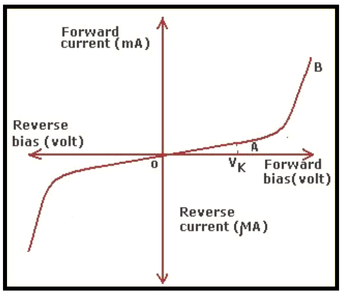
The junction resistance rises to an extremely high level and virtually no current flows through the circuit.

In practice, however, a very modest current of the order of micro-amperes travels across the circuit. Because of the minority carriers in the junction, this is known as reverse saturation current.



P-N Junction Diode in Reverse Bias

(b) The V-I Characteristics curve for p-n junction diode for forward bias and reverse bias



66.

(a) Draw a labeled circuit diagram to obtain characteristics curve of an npn transistor in common emitter configuration.

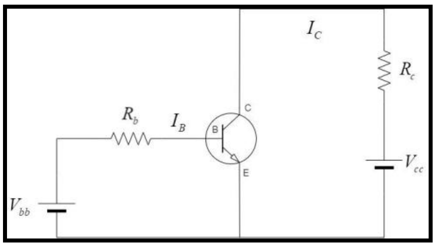
(b) Plot the curves for its:

(i) input and (ii) output characteristics

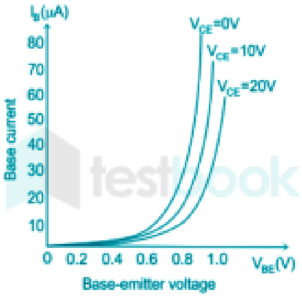
(c) In a transistor, when 1 mA change in emitter current changes collector current by 0.99 mA. Calculate the ac current gain. **[PYQ NIOS Oct 2022]**

Answer:

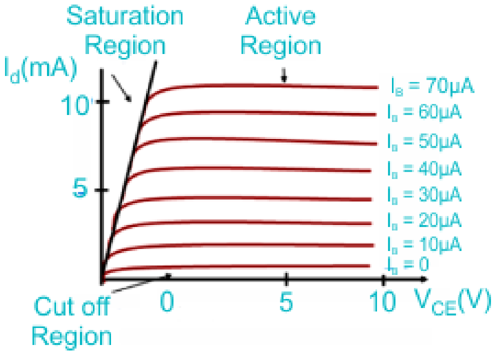
(a) A labeled circuit diagram to obtain characteristics curve of an npn transistor in common emitter configuration is as follows:



(b) Curves for its input and output



I/P characteristics CEconfiguartion



Output characteristics of common Emitter configuration

(c) I_C = 0.99 Ma

I_E = 1mA

$$\propto = \frac{I_C}{I_E} = \frac{0.99\times 10^{-3}}{1\times10^{-3}} = 0.99$$

$I_B = I_E - I_C$

$I_B = (1 - 0.99) \times 10^{-3}$ = 0.01 Ma

$$\beta = \frac{I_C}{I_B} = \frac{0.99\times 10^{-3}}{0.1\times10^{-3}} = 99$$